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EPA REGIONAL OXIDANT MODEL:  
ROM1 EVALUATION FOR 3-4 AUGUST 1979

by

Kenneth L. Schere  
Meteorology and Assessment Division  
Atmospheric Sciences Research Laboratory  
Research Triangle Park, North Carolina 27711

ATMOSPHERIC SCIENCES RESEARCH LABORATORY  
OFFICE OF RESEARCH AND DEVELOPMENT  
U.S. ENVIRONMENTAL PROTECTION AGENCY  
RESEARCH TRIANGLE PARK, NORTH CAROLINA 27711

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#### AFFILIATION

Mr. Schere is on assignment to the Meteorology and Assessment Division, Atmospheric Sciences Research Laboratory, from the National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

## ABSTRACT

The first generation U.S. Environmental Protection Agency Regional Oxidant Model (ROM1) has been tested and evaluated for O<sub>3</sub> predictions on a two-day test case episode in the northeast U.S. during 3-4 August 1979. The period was characterized by relatively high O<sub>3</sub> concentrations in the southern Great Lakes area where clear skies persisted. Intermittent periods of relatively high O<sub>3</sub> levels existed near some of the eastern seaboard cities where partly cloudy skies alternated with clouds and showers in the vicinity of a stationary frontal zone. The highest observed hour-average O<sub>3</sub> level monitored at a surface site during the period was 159 ppb.

The ROM1 incorporates some simplifying assumptions and algorithms as compared to the second generation version, ROM2, which is in preliminary testing stages now and will eventually become the production version of the model. Among these simplifications are the assumptions of flat terrain as well as temporally and spatially constant grid cell sizes. Also, preliminary versions of the chemical kinetic mechanism and source emissions inventory have been used. Evaluation results for this test episode showed that the ROM1 had approximately a 6% average underprediction of O<sub>3</sub> when all hours and surface monitoring sites were considered. When the data were restricted to only those observed and predicted pairs of O<sub>3</sub> values greater than 50 ppb the average performance improved to a 1% underprediction. The evaluation aspect concerned with estimating maximum daily O<sub>3</sub> values showed an 8% average underprediction of the maximum value for the restricted data subset. An analysis of individual O<sub>3</sub> plumes during the episode showed average model performance for predicting the plume maximum concentration level to lie between 22% underprediction and 38% overprediction.

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## SECTION 1

### INTRODUCTION

The United States Environmental Protection Agency's Regional Oxidant Model (ROM) has been under development and testing for a number of years. The model formulation and developmental tests have been thoroughly documented in a series of reports (Lamb, 1983, 1984, 1985). The ROM attempts to simulate all of the important physical and chemical processes that affect the generation and dispersion of photochemical smog on regional scales (up to 1000 km). In the present configuration of the ROM domain, the model's horizontal resolution is approximately 18.5 km. In the vertical there are 3 1/2 layers. The first and second layers encompass most of the planetary boundary layer above the surface of the earth and the third layer is the cloud layer extending from cloud base to near the tops of any cumulus-type clouds. Layer 0 is a shallow layer adjacent to the surface designed to treat sub-grid scale effects in the ROM. It is handled in a diagnostic manner within the model.

The horizontal spatial extent of the first ROM application is shown in Figure 1. This model domain includes the areas covered by special field monitoring projects during the summers of 1979 and 1980. During these projects highly resolved air quality, meteorological, and source emissions data bases were developed for the study area, hereafter referred to as the NEROS region (Northeast Regional Oxidant Study). The field projects conducted in the NEROS region included those of the 1980 Northeast Corridor Regional Modeling Project (NECRMP), focusing on the larger urban areas bordering the Atlantic coast, as well as the regionally-oriented NEROS projects (Possiel and Freas, 1982; Vaughan, 1985). The specific episode studied in this report occurred during 3-4 August 1979, during the first NEROS field project. Meteorological and air quality details of this episode are described in the next section.

The ROM version used in this modeling study is the first generation model (ROM1). Several aspects of the ROM1 modeling system are in preliminary or simpler form as compared to that described in the full ROM documentation (Lamb, 1983, 1984, 1985). These aspects include the following considerations:

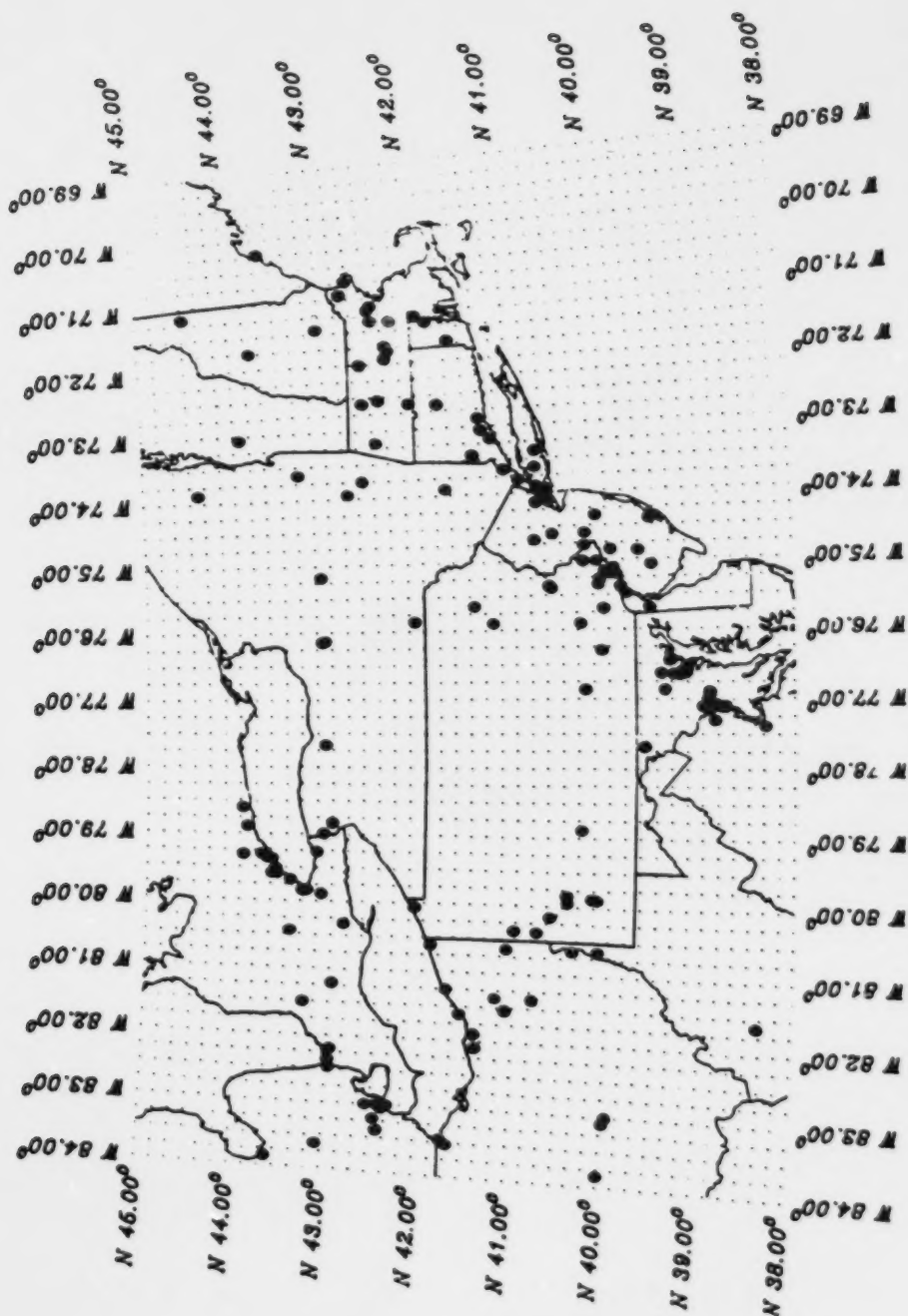


Figure 1. ROM grid resolution in the NEROS study region. O<sub>3</sub> monitoring stations operating during the 3-4 August 1979 period are indicated by dots.

- (1) The source emissions inventory is the preliminary one developed during the NECRMP project. It does not contain biogenic sources of hydrocarbon species. Eventually, the newer NAPAP (National Acid Precipitation Assessment Program) emissions inventory, including biogenic emissions, will be used in ROM studies of the NERUS region.
- (2) The wind fields generated to drive the horizontal advection component of the model are derived, for all 3 model layers, from objective interpolation of measured surface and upper air winds. Later wind field processors for layer 1 will include a predictive hydrodynamic model of winds in the nighttime boundary layer.
- (3) Vertical cloud flux parameters are now pre-specified in the ROM1. Later versions will incorporate a cloud flux module that calculates vertical flux velocities based on a computed moist convection level for each grid cell.
- (4) A single wind field interpolation (realization) for each hour of model simulation is used for each of the ROM1's three prognostic layers. The wind processor currently under development provides multiple wind realizations for each hour with a probability-weighted likelihood of occurrence for each.
- (5) The vertical dimension of all grid cells in any given layer in ROM1 is constant in space and time. Also, a flat surface is assumed to exist beneath the model domain. The relevant vertical dimensions are 40 m for layer 0, 400 m for layer 1, 800 m for layer 2, and 800 m for layer 3. The next model version will provide for terrain relief at the surface (no flat surface assumption made) and for spatially and temporally variable cell heights across the domain. The vertical size of any given cell will be a function of the locally occurring physical phenomena.

The model features described above that are not yet implemented will become part of the second generation regional model, ROM2, scheduled to

become operational shortly. The final major difference between ROM1 and ROM2 is in the chemical kinetic mechanism. ROM1 contains a 23-species, 36 reaction step mechanism developed by Dr. Ken Demerjian of EPA, while ROM2 will contain a 28-species, 70 reaction step mechanism, Carbon Bond IV (CB-IV), developed by Dr. Gary Whitten of Systems Applications, Inc. The CB-IV mechanism contains an explicit reaction pathway for the biogenic hydrocarbon species, isoprene. This will allow the ROM2 to accommodate biogenic species in the source emissions inventory; ROM1 has no provision for biogenic species.

This report discusses the evaluation of ROM1 results for O<sub>3</sub> predictions on the 3-4 August 1979 episode in the NEROS region. The evaluation has been structured in a manner designed to elicit the ROM1's performance for prediction of hourly and maximum O<sub>3</sub> concentrations. The primary function of the Regional Oxidant Model is to evaluate the effects of various emission control strategies on the maximum O<sub>3</sub> concentrations generated by these precursor emissions. Ideally, the model would be tested on two data bases separated by a number of years encompassing actual changes in emission inventories and the resulting air quality. This goal is not yet attainable because of a scarcity in regional scale emission inventory data for previous years, although in the future such a test should be possible. At present our confidence in the ROM1's ability to replicate the spatial and temporal O<sub>3</sub> patterns resulting from the base year precursor source emissions inventory is a necessary step in the evaluation process. This step is necessary because the non-linear physical and chemical reaction effects that result in the production of ambient O<sub>3</sub> concentrations preclude one from assuming that changes in precursor emissions may be linearly mapped into changes in the resulting O<sub>3</sub>. It is necessary to verify photochemical models in an absolute sense for model predictions as well as relatively for source emissions changes. The sufficient condition for evaluating the Regional Oxidant Model must await the establishment of multiple base year emission inventories separated in time by a number of years to verify actual ambient air quality changes with respect to emissions changes.

The present task therefore is to evaluate the absolute magnitudes and patterns of O<sub>3</sub> concentrations predicted by the ROM1. The planned procedures for model evaluation for ambient simulations have been documented

in a previous report (Scherre and Fabrick, 1985). We will follow the protocol discussed therein to the extent that the available data and resources permit. The evaluation procedure includes several levels of analysis. The first level explores the observed data set to bring out the important features, both on temporal and spatial scales. This includes an analysis of the existing meteorological conditions during the simulation period to provide a background context in which the air quality conditions evolve. Next the spatial and temporal patterns of  $O_3$  concentrations from surface monitors and aircraft sampling are studied to highlight the significant phenomena occurring in the modeling domain. It is these features that the model should be able to replicate during the simulation.

The next level of analysis explores the comparison between ambient  $O_3$  observations and the model-predicted concentrations. First, the comparison is made for all hourly observations at all monitoring sites. This analysis brings out gross features of model performance including any systematic trends in model bias. Subsets of the full data set are used to explore particular aspects of the comparisons, such as whether the model predicts  $O_3$  concentrations more accurately at higher values than lower values. Next, comparisons are made between maximum daily  $O_3$  concentrations at surface monitoring sites and model predictions of  $O_3$  maxima. These comparisons are performed in a number of ways. First, daily maxima at all surface monitoring locations are matched with model predictions at those locations. The analysis on these data pairs is conducted with statistical tests and graphical analyses such as scatterplots and is designed to elicit the ability of the model to predict  $O_3$  maxima over the entire modeling domain. Of course, over the size area contained in a regional modeling domain the areas of maximum  $O_3$  are generated from different precursor source emissions regions and are affected by different meteorological influences. Therefore, in an effort to isolate the model performance for a given source area,  $O_3$  plumes are individually identified and the model's ability to predict maximum  $O_3$  concentrations within the plume is evaluated. Both types of maximum values analyses are necessary in conjunction with assessing the ROM1 as a tool for emission control

strategy assessment. Examining all daily  $O_3$  maximum values together illustrates the potential effects of a control strategy on the entire region while individual plumes will highlight any  $O_3$  reductions from the controls on a particular urban source area.

The inherent uncertainty in model predictions on the regional scale should be factored into an analysis of the results from the Regional Oxidant Model. This uncertainty evolves from measurement and estimation errors in model input parameters as well as uncertainty from the empirical parameterizations used throughout the modeling system. Perhaps the greatest area of uncertainty though is in the horizontal transport portion of the model. Lamb (1983) discusses this aspect of model uncertainty. Basically the heart of the problem is that there does not exist a unique transport field that can be determined for a model simulation based on the existing wind monitoring network. In fact, on the 1000-km regional scale it would be impractical to design a network dense enough to unambiguously determine the transport for the model.

In the analyses of model results presented here for the entire model domain at once (i.e. all receptor locations considered together) this transport uncertainty is not considered. Thus if the simulated transport field carries a plume of  $O_3$  in a slightly different direction from the actual field such that a monitoring site that was directly affected by the plume appears to have been bypassed in the simulation, a large underpredictive bias will result. The converse situation will result in an overpredictive bias. In the analysis for individual plume maximum  $O_3$  concentrations the transport uncertainty is considered in that the observed and predicted plumes of  $O_3$  from major source areas are identified separately by the observations and predictions. Maximum  $O_3$  values are matched in such a way as to compensate for the transport uncertainty.

The second generation, ROM2, modeling system will include an objective method of interpolating winds from the existing observation network that will produce a family of legitimate wind field "realizations", each with

an assigned probability of occurrence. This will enable the model evaluation analysis to directly consider the effects of inherent transport uncertainty. The single wind field used in the ROM1 simulation is considered the field with the greatest probability of occurrence.

Figure 1 shows the extent of the ROM1 domain in the NEROS application. There are 60 cells in the E-W direction and 42 cells in the N-S direction. The dimensions of each individual grid cell are 15 minutes of longitude (E-W) and 10 minutes of latitude (N-S), or about 18.5 km square cells. There are approximately 200 SAROAD air monitoring sites measuring hourly ambient O<sub>3</sub> concentrations within the NEROS region, although at any given day and hour only a subset of these sites generally is actively measuring. The locations of the SAROAD monitoring stations measuring O<sub>3</sub> during the 2 day modeling episode are shown in the figure. Appendix A contains a list of those stations (as well as others) along with their grid coordinates.

## SECTION 2

### TEST EPISODE: 3-4 AUGUST 1979

The data base used here to test and evaluate the  $O_3$  simulation results from ROM1 corresponds to that of 3-4 August 1979. This 2-day period occurred during the 1979 NEROS summer field study which included enhanced meteorological and air quality measurements in the northeast United States. A detailed description of the NEROS data base is not included here, but a summary can be found in the ROM evaluation protocol report (Schere and Fabrick, 1985) and further details are in the reports of Possiel and Freas (1982), Freas (1983), Vaughan (1985), and others. This section discusses the meteorological conditions prevalent during the test period as well as the observed surface  $O_3$  monitoring data.

#### Meteorological Conditions

On 2 August 1979, a weak area of low pressure traveled northeast from the Illinois-Indiana area through Michigan into Ontario. The trailing cold front moved eastward just off the Atlantic coast by the morning of 3 August, and became stationary. A low pressure area developed on the stationary front near the coast of Virginia and widespread cloudiness and showers were prevalent along the Atlantic seaboard, traveling generally from the mid-Atlantic coast on 3 August to the northeast coast on 4 August. A large area of high pressure built into the eastern U.S. from the midwest after the passage of the cold front. Aside from being slightly drier the newer air mass was not substantially different than the older air mass. Highest temperatures throughout the NEROS study area were generally from the mid to upper 80's ( $^{\circ}F$ ). Figures 2 and 3 show the 7a.m. (EST) surface weather map features for the U.S. for the 2 day period under study.

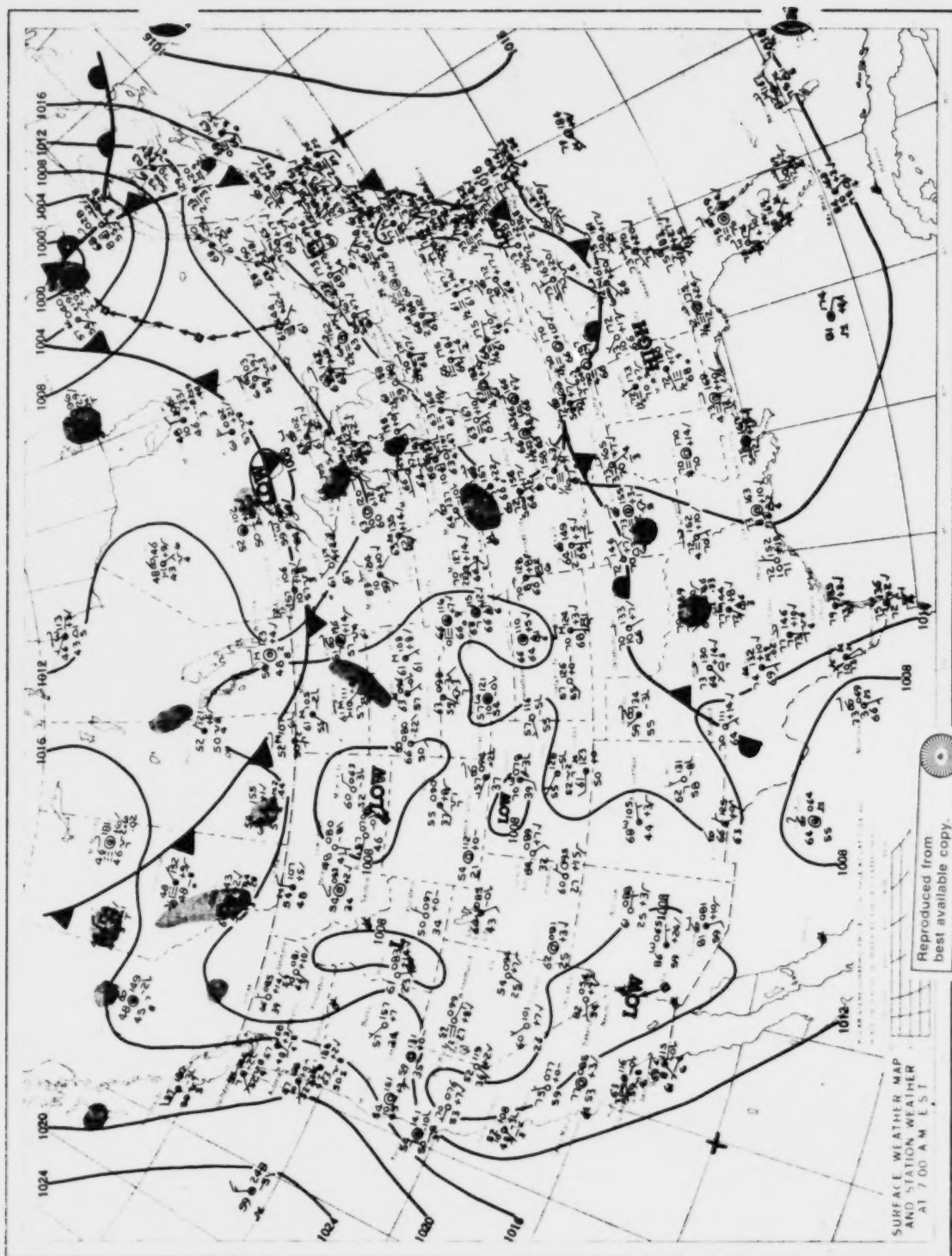


Figure 2. Surface weather map for 3 August 1979.

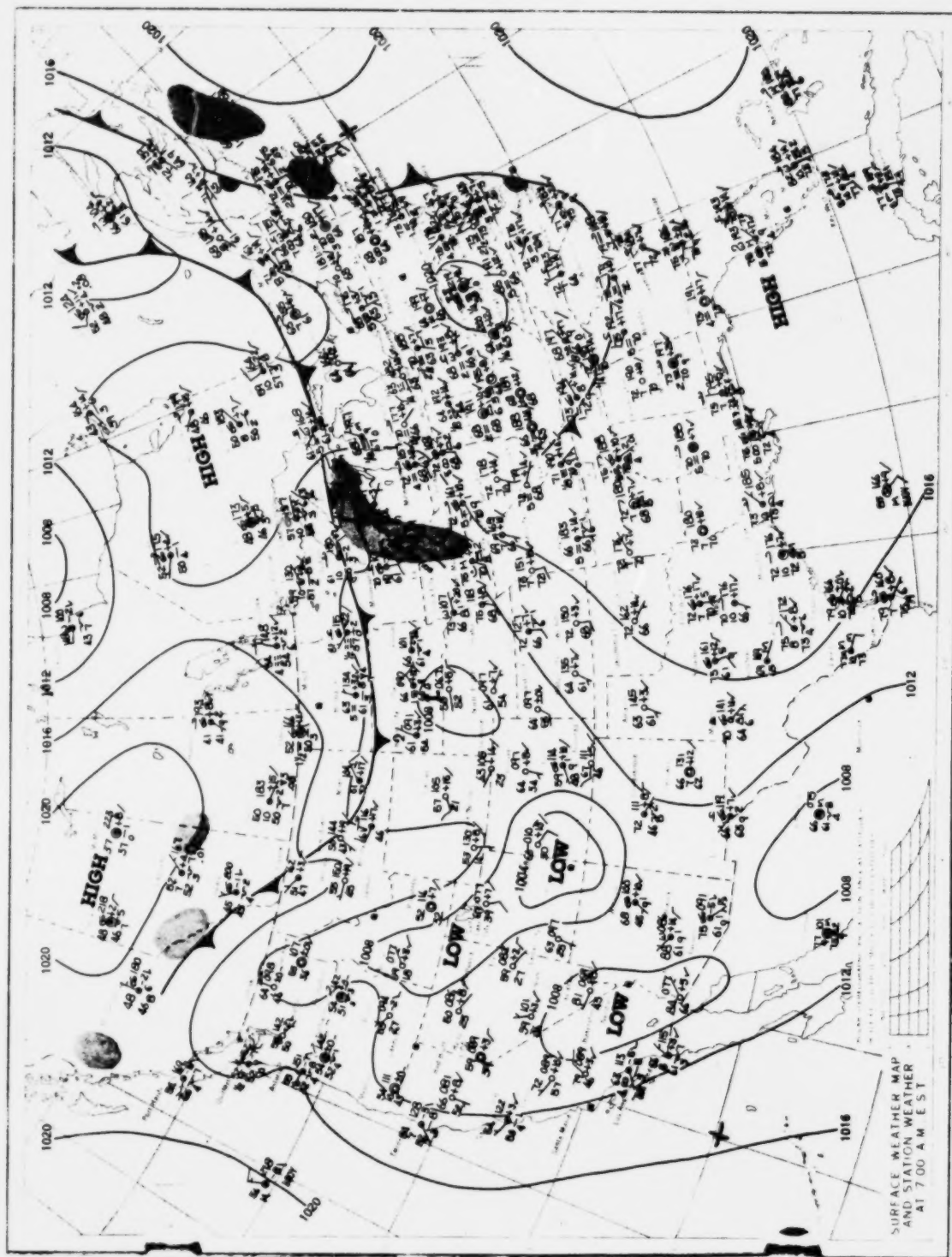


Figure 3. Surface weather map for 4 August 1979.

The atmospheric pressure gradient aloft was very weak, with accompanying low wind speeds. On 3 August, the 500 mb flow was generally from the SW ranging in speed from 5 m/s over Virginia to 20 m/s over New York and New England. On 4 August, the 500 mb flow was from the W through SW at speeds of 5-10 m/s over the NEROS region. Surface winds were of lighter speed and similar direction.

Examining the surface observation record from selected stations during this period shows the western part of the NEROS region (Ohio, western Pennsylvania and New York, Ontario) to be generally cloud-free or with scattered high cirrus-type clouds. Haze was reported at many ground stations. The eastern seaboard cities were generally under heavy cloud cover with occasional showers. For instance, Washington, D.C. reported ceiling heights of 2000 to 6500 feet above ground on 3 August, with rain showers. By the next day the cloudy area had moved north and Washington was generally clear with some haze. On 3 August, Bridgeport, Connecticut showed generally clear skies, although to the south and east heavier cloudiness was reported. The next day Bridgeport was under low clouds with showers. In contrast the station reports from Buffalo, New York and Detroit, Michigan reported mostly clear skies throughout the period.

In assessing the impact of the synoptic meteorological features on the photochemical smog potential over the NEROS study area it seems clear that the area of greatest interest would be the Ohio valley through the Great Lakes into Ontario for this 2 day period. Wind speeds were light but of persistent direction here and skies were clear. The eastern seaboard cities were under partially clear skies for only part of the period, or not at all. Surface wind directions were quite variable here also. The effects of these meteorological conditions would be to suppress the photochemical potential in the East, although for brief periods during the daytime when skies cleared there would be a local increase in the potential.

## Air Quality Conditions

Figures 4 and 5 display the maximum values of hourly averaged  $O_3$  measured at the U.S. SAROAD monitoring stations in and just outside of the ROM1 model domain and the Ontario stations within the domain for 3 August and 4 August, respectively. The surface stations are not distributed evenly across the region. They tend to be clustered in the vicinity of urban areas, leaving large portions of the model domain with little or no surface monitored  $O_3$  data. Scarcity of data is especially apparent in the region stretching from the Ohio Valley northeast through central and northern New York state, except for the Pittsburgh area. Model performance in the central section of the grid will therefore be difficult to judge, except in a gross sense. The Northeast corridor of cities is well represented, as is, to a lesser degree, the industrialized areas near the Great Lakes.

The 3-4 August 1979 period was not a major episode for  $O_3$ , although values exceeded 100 ppb in selected areas. On 3 August, despite the cloud cover over the mid-Atlantic seaboard some  $O_3$  values reached between 100 and 115 ppb in the Washington and Philadelphia areas and between 120 and 130 ppb in the New Jersey, New York and Connecticut area, where there was less cloud cover on that day. Measured  $O_3$  values around 100 ppb were found downwind of Detroit and Toronto. Other measured values in the vicinity of the Great Lakes and Ohio Valley were not high, except for near the southeast shore of Lake Erie, where Conneaut, Ohio recorded 159 ppb as the daily maximum. The diurnal record of measured  $O_3$  at that station is an interesting one. Hourly concentrations at Conneaut from 0800 to 1200 h, LST are 29, 40, 82, 100 and 132 ppb. The very rapid rise in concentration between 0900 and 1000 h might suggest the entrainment of  $O_3$  from a plume aloft rather than from local photochemical generation near the surface. Measured  $O_3$  data from aircraft flights during the NEROS study should help determine the validity of this premise.

On 4 August, the overcast and rainy conditions along the Atlantic coast from New York northward did, in fact, seem to suppress  $O_3$  generation. South of New York however, relatively high levels were measured near the Philadelphia

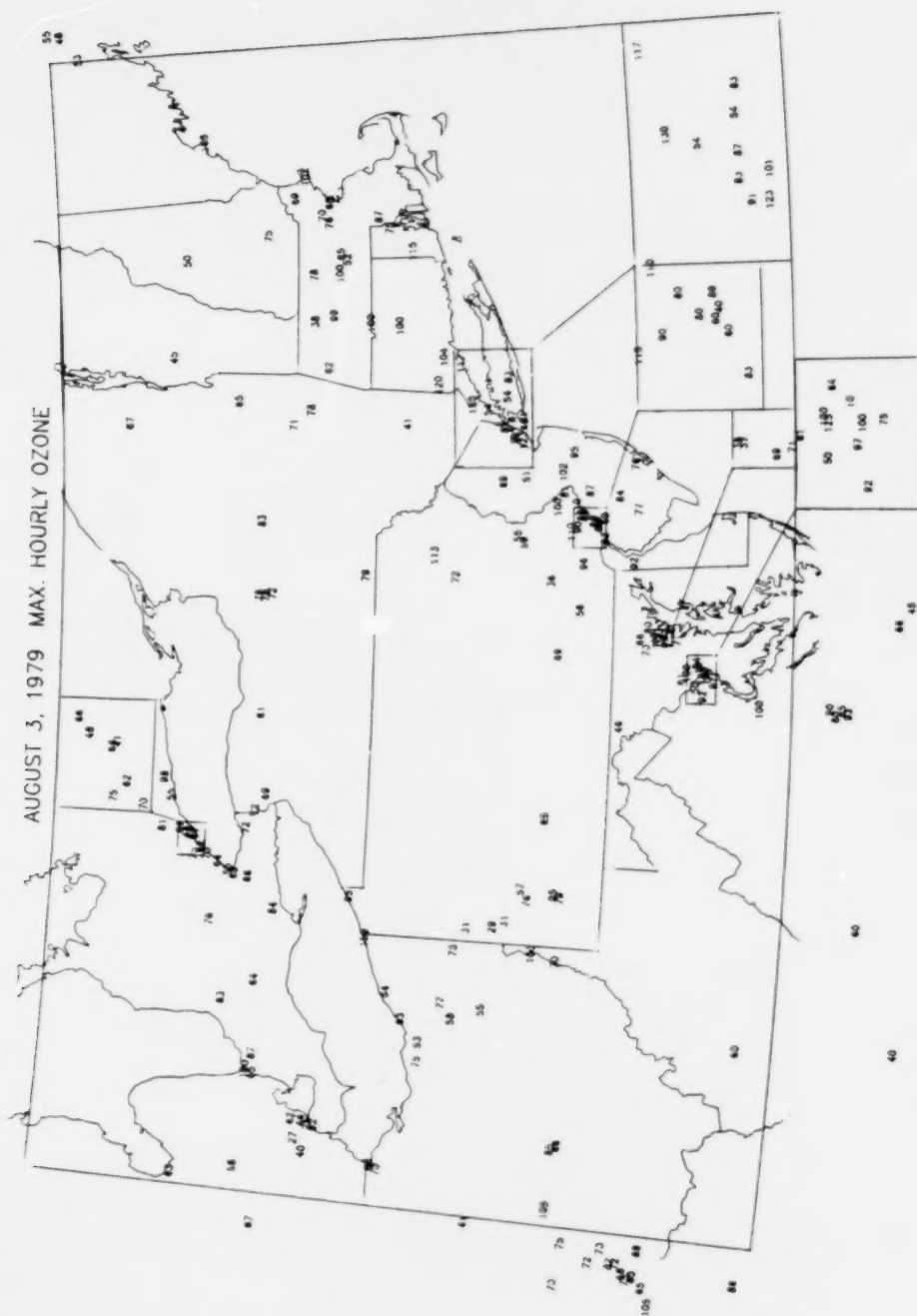


Figure 4. Maximum hourly values of  $O_3$  observed at surface monitoring sites on 3 Aug. 1979.

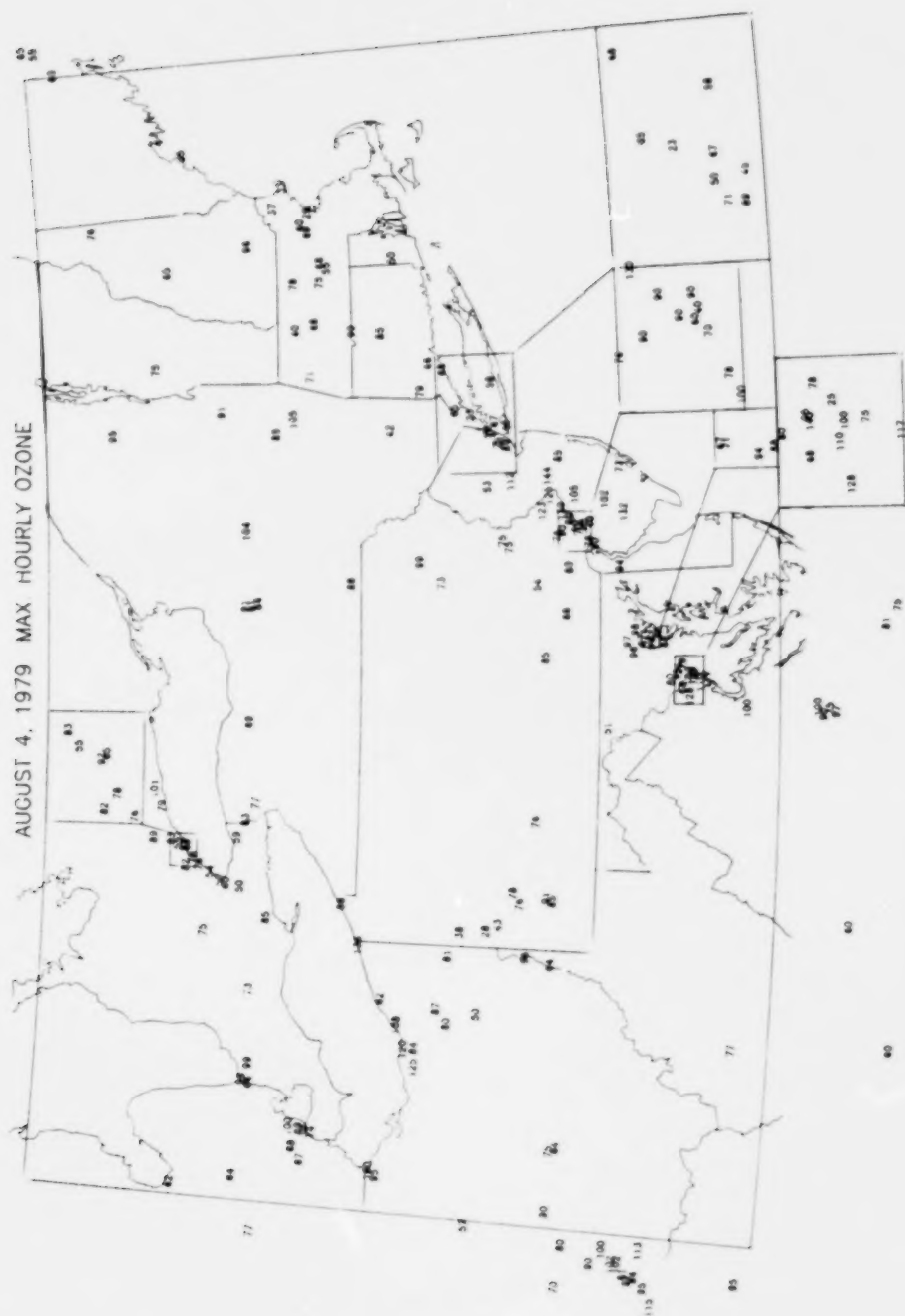


Figure 5. Maximum hourly values of  $O_3$  observed at surface monitoring sites on 4 Aug. 1979.

area (143 ppb) and Washington, D.C. (139 ppb) where skies had cleared. Several observation stations along the south shore of Lake Erie reported maximum O<sub>3</sub> levels from 120-135 ppb. Most other areas of the NEROS region reported low values, except for a few observations near 100 ppb downwind of Detroit and Toronto.

Numerous aircraft transects were made over the NEROS region during the 3-4 August period. Participating aircraft included those from Washington State University (WSU), Research Triangle Institute (RTI), and Brookhaven National Lab (BNL). A listing of the flights made is given in Table 1 and the approximate flight paths are shown in Figures 6 and 7 for 3 August and 4 August, respectively. The temporal progression of flights from west to east reflects the Lagrangian sampling strategy of attempting to follow an area of high pollutant concentrations over the Midwest as it is transported east. Flights outside of the Lagrangian sampling were made as well.

The aircraft O<sub>3</sub> measurements were made mostly within the boundary layer, within 2 km of the earth's surface. The sampling altitude corresponds generally to layers 2 and 3 of ROM1. Aircraft observations have the advantage of being more representative of the boundary layer than measurements made only at the surface, but also have the disadvantage (from the perspective of Eulerian modeling) of being very short-lived at any one location. The aircraft measurements of O<sub>3</sub> help determine the regional background O<sub>3</sub> burden. Flight A, the RTI aircraft transect over the Ohio-Lake Erie region during midday on 3 August showed 60-70 ppb of O<sub>3</sub> in the upper portion of the troposphere and 70-80 ppb of O<sub>3</sub> in the lower portion. Slightly lower values (by about 5-10 ppb) were seen on the return portion of the RTI flight that night, flight C. The remaining flights made on 3 August, flights B and D by WSU, showed somewhat higher background O<sub>3</sub> values in the central portion of the NEROS region. The range here was 70-90 ppb O<sub>3</sub> during the afternoon and late evening, with higher values to the north in an area of relatively high O<sub>3</sub> near the Great Lakes. The general boundary layer O<sub>3</sub> pattern on 3 August was constructed by Clarke et al. (1983) from the aircraft measurements made on that day, and is reproduced here in Figure 8. It shows the area of high O<sub>3</sub> concentrations mainly over

TABLE 1. SUMMARY OF NEROS AIRCRAFT SAMPLING FLIGHTS -  
3-4 AUGUST 1979

| Flight | Date        | Operator | Start<br>Time<br>(h, LST) | End<br>Time<br>(h, LST) | Start<br>Location  | End<br>Location    |
|--------|-------------|----------|---------------------------|-------------------------|--------------------|--------------------|
| A      | 3 Aug. 1979 | RTI      | 11:54                     | 13:59                   | 39°48'N<br>82°40'W | 43°55'N<br>79°25'W |
| B      | 3 Aug. 1979 | WSU      | 17:09                     | 19:37                   | 39°18'N<br>81°32'W | 43°20'N<br>78°10'W |
| C      | 3 Aug. 1979 | RTI      | 22:31                     | 00:42                   | 43°55'N<br>79°25'W | 39°48'N<br>82°40'W |
| D      | 3 Aug. 1979 | WSU      | 23:07                     | 02:25                   | 43°07'N<br>77°40'W | 40°07'N<br>76°18'W |
| E      | 4 Aug. 1979 | BNL      | 07:03                     | 09:35                   | 42°51'N<br>76°19'W | 39°05'N<br>78°45'W |
| F      | 4 Aug. 1979 | RTI      | 12:47                     | 15:21                   | 39°08'N<br>82°05'W | 42°56'N<br>82°35'W |
| G      | 4 Aug. 1979 | BNL      | 13:18                     | 15:32                   | 39°28'N<br>77°26'W | 41°23'N<br>73°50'W |
| H      | 4 Aug. 1979 | WSU      | 17:20                     | 19:15                   | 40°07'N<br>76°18'W | 41°10'N<br>80°40'W |
| I      | 4 Aug. 1979 | RTI      | 20:43                     | 23:06                   | 42°56'N<br>82°35'W | 39°08'N<br>82°05'W |

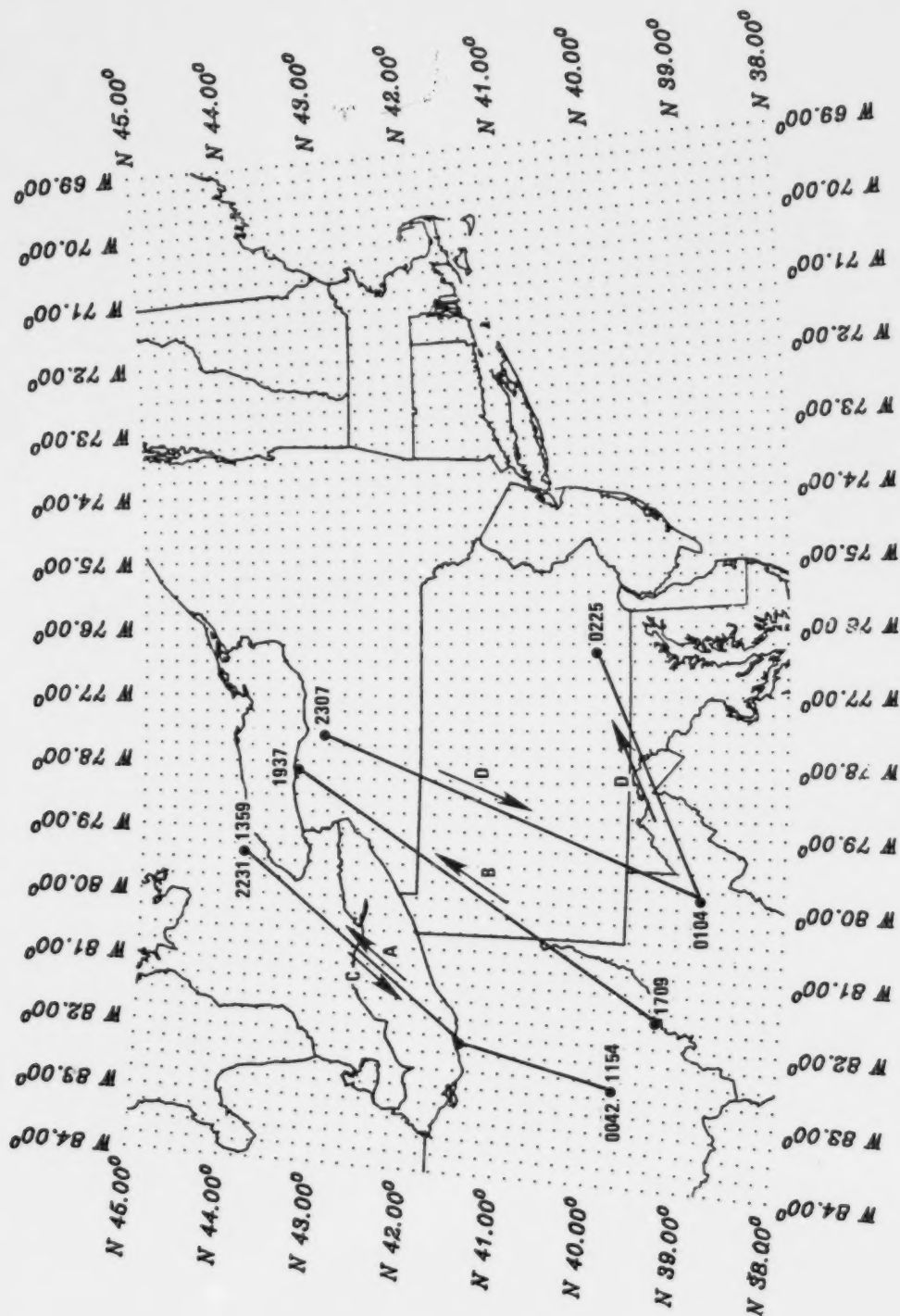


Figure 6. Approximate aircraft sampling flight paths conducted during the NEROS study on 3 August 1979.

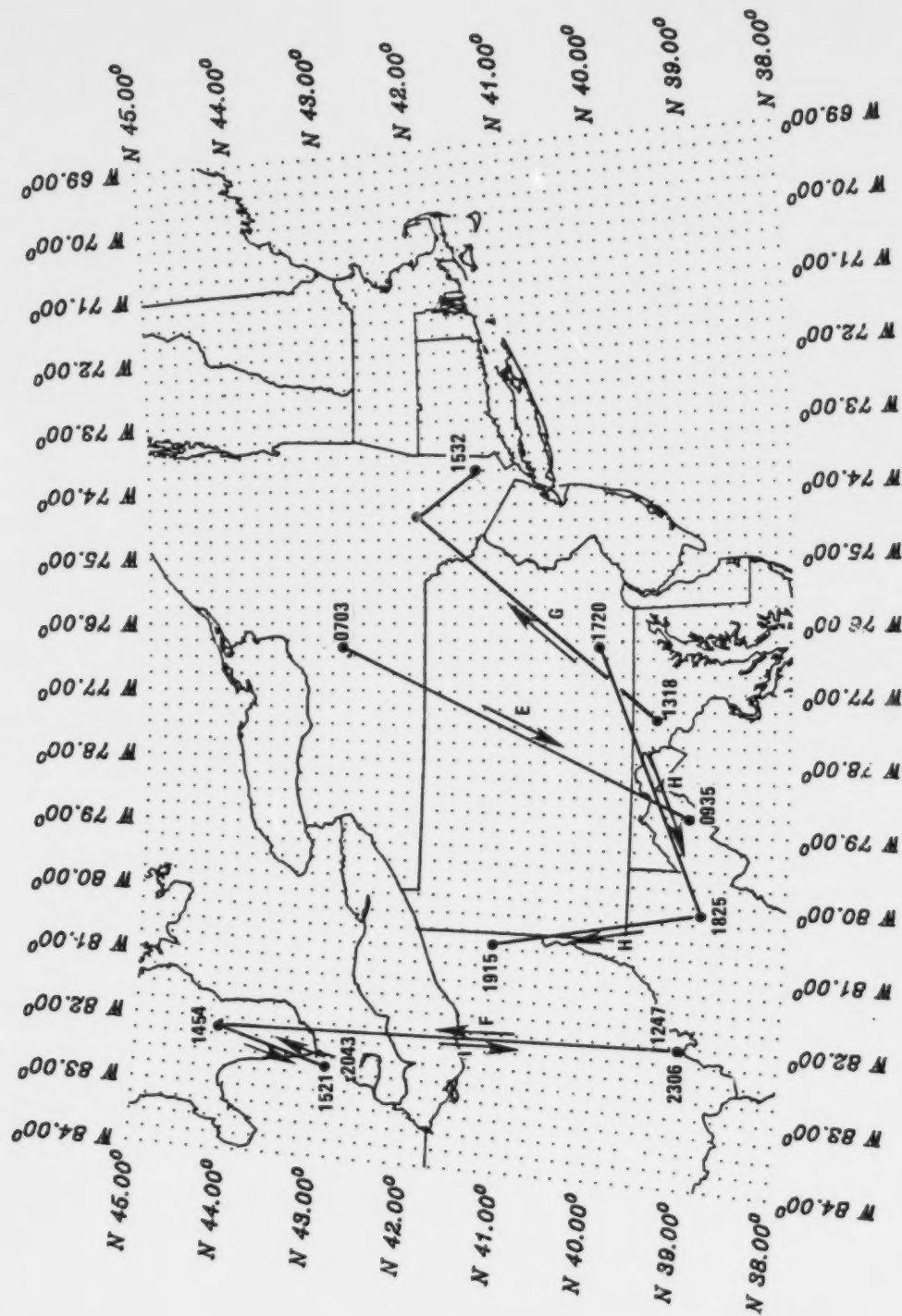


Figure 7. Approximate aircraft sampling flight paths conducted during the NEROS study on 4 August 1979.

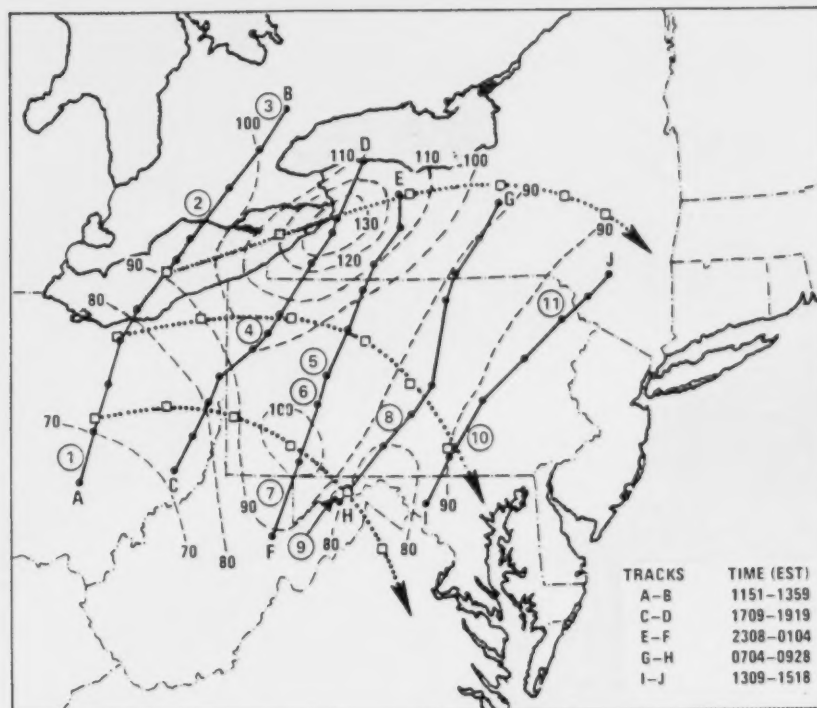


Figure 8. Aircraft sampling flight tracks and  $O_3$  concentrations (ppb) near the center of the mixed layer (dashed lines) during the 3-4 August 1979 period. (from Clarke et al., 1983)

western New York and Pennsylvania, with the highest point values between 160 and 170 ppb. This is just to the east of the surface monitoring site at Conneaut, Ohio where a maximum surface value of 159 ppb was recorded the same day. The aircraft data add further evidence to a verification of the premise that there existed an area of elevated  $O_3$  concentrations aloft in the boundary layer to the south and east of the Lake Erie shoreline and possibly over the lake itself on 3 August. The timing and location of this area of high  $O_3$  concentrations indicates that it was not generated on this day, but rather advected here from another time and location, quite possibly from Detroit and the heavy industrial areas to the west of Lake Erie. The wind flow over this region the previous day had been from the west and southwest directions, with a stronger westerly component immediately behind the weak cold front that passed through on 2 August. Clarke et al. (1983) suggest that the higher pollutant loading seen here may have originated as far west as Chicago, given the results of a back trajectory analysis.

The first aircraft transect made on the morning of 4 August was a particularly interesting one because it sampled in an area of the NEROS region that is sparse in surface monitoring locations. Flight E seen on Figure 7 was conducted by BNL and proceeded from a point south of Syracuse, NY to easternmost West Virginia. On this flight  $O_3$  values in the boundary layer were seen to fluctuate in the range of 70-80 ppb over New York and Pennsylvania and 60-70 ppb over Maryland and West Virginia. A similar pattern of concentrations was seen on the return flight (G) that afternoon. The transect for flight G proceeded from south to north and to the east of transect E. Again no pronounced increases in  $O_3$  concentration during the flight were observed here, and the general boundary layer values were 70-80 ppb. The WSU aircraft conducted a late afternoon flight on 4 August consisting of 2 legs. The first leg of flight H proceeded from southeast Pennsylvania to West Virginia. Boundary layer  $O_3$  concentrations along this leg were in the 70-80 ppb range. The second leg of the flight went north from West Virginia to northeast Ohio. Here the concentrations of  $O_3$  were more in the 50-70 ppb range within the boundary layer. The RTI aircraft made 2 north-south transects along the same path on 4 August. An afternoon flight from southern Ohio to Lake Huron

showed  $O_3$  concentrations of 70-80 ppb generally in the boundary layer, with a few exceptions. Concentrations of around 90 ppb were detected southeast of Columbus and also west of Akron. The aircraft apparently encountered an  $O_3$  plume southeast of Detroit over Lake Erie extending into southwestern Ontario. Concentrations of 90-150 ppb  $O_3$  were detected in the plume. The relative compactness of the plume and the distance downwind of Detroit indicate that the plume probably represents photochemical activity from that city on 4 August. The return flight occurring during late evening along the same path showed a broad  $O_3$  plume now northeast of Detroit with peak concentrations of 120 ppb extending over about a 35 km cross-section. South of this plume  $O_3$  concentrations were generally in the 65-75 ppb range with an increase to about 90 ppb in southeast Ohio.

In general, the aircraft sampling during this 2-day episode over the NERUS region indicated widespread boundary layer  $O_3$  levels of 70-80 ppb with some areas slightly higher or lower than this range at times. The aircraft sampling showed the presence of 2 pronounced  $O_3$  plumes during the period in the areas covered by the transects. The first was a large area of  $O_3$  from an aged plume over western New York on 3 August (see Figure 8) and the second was an urban-scale plume, probably from Detroit, over western Ontario on 4 August. Aircraft sampling downwind of other major urban source areas in the NERUS region was either insufficient or nonexistent in order to detect  $O_3$  plumes.

Section 3 presents detailed comparisons of the hourly averaged surface  $O_3$  concentrations and the corresponding model predictions. Measurements of  $O_3$  concentrations aloft from aircraft monitors are also used in the analysis to help resolve particular features of the concentration pattern.

#### ROM1 Initial and Boundary Concentrations

Any mass-conservative grid model of atmospheric air pollution, including ROM1, is sensitive to the initial field of mass within the

modeling domain as well as the mass flux across inflow boundaries during the simulation. The initial mass field specified as a model input can remain within the model domain and exert considerable influence on simulation results for hours or days, depending upon the spatial scale of the model, wind transport speeds, and source emissions distributions and flux rates. In urban scale modeling the initial field is typically advected out of the modeling domain within a few hours after the start of simulation. Monitoring networks on this scale are often sufficient to adequately specify the initial concentrations of the major pollutant species of interest. On the larger regional scale however more problems are encountered in specifying a proper initial concentration field.

One major concern is the density of monitoring stations over a 1000-km regional scale model domain. Figure 1 demonstrates that the density of  $O_3$  monitors in the standard U.S. SAROAD network is not uniform. Major urban areas are covered fairly well but large areas of the domain are unmonitored. Interpolation across such large distances may not be reliable. Aircraft sampling may help to some degree, but the transects available are relatively few and those taken near model initialization time are fewer still. The density of monitors for species other than  $O_3$ , such as  $NO_x$  and hydrocarbons, is considerably less than that for  $O_3$ , making the initialization problem worse because these precursor species are important in the photochemical generation of  $O_3$ . The uncertainty in the initial concentration estimates is further compounded by the transport speeds. Days may elapse before the initial mass field is completely flushed out of a regional model domain. For instance, in a 1000-km model domain with a lateral transport wind speed of 5 m/sec it would be 55 hours before the initial mass is completely transported out. In the interim simulation period errors in the initial field specification would propagate through the chemical interactions to the model species predictions.

The first attempt at simulating the 3-4 August 1979 period with the ROM1 included an estimate of the initial concentration field at 00 h, LST on 3 August over the model domain. Five "categories" of grid cells were determined, based mainly on land use, where the same set of initial concentration values

were used in all cells of a given category. The categories ranged from a remote or wilderness class to an urban-industrial class. Ambient observations of  $O_3$  near model initialization time were studied for each class of cells and estimates of the initial  $O_3$  value within each class were made. Data observations of  $NO_x$  were very sparse and those of hydrocarbons were essentially nonexistent, so estimates of these concentration values were made for each category of grid cells based on chemical equilibrium considerations of all the reactive species. It became clear in examining the simulation results for the 2-day episode using this method of model initialization that it would not be possible to distinguish between model  $O_3$  results based on precursor source emissions input to the simulation or model results as artifacts of the specified initial field. For example, the large area of  $O_3$  over western New York (see Figure 8) appeared in the simulation results primarily because of heavy initial mass loadings of  $O_3$ ,  $NO_x$ , and hydrocarbons over the Ohio-Lake Erie vicinity. In attempting to evaluate model results for  $O_3$  we are interested primarily in analyzing the model's ability to generate  $O_3$  patterns from the given source emissions distribution because the ROM1 will eventually be asked to judge the effects on  $O_3$  of proposed changes in the source emissions input function. The effects of initial conditions must therefore be minimized in any simulations performed with a regional model.

We minimize the influence of initial conditions by specifying tropospheric background "clean" conditions throughout the model domain. In conjunction with this procedure it will be necessary to begin model simulation at a relatively "clean" period of time throughout the domain also, such as after the passage of a cold front with an attendant air mass exchange. In future work with ROM2 we will use this initialization procedure at the start of a long period (1-4 weeks) simulation. This longer period will also insure a minimal dependence of model results on initial concentrations.

For the 2-day episode at hand, however, the simulation was performed again with tropospheric clean initial conditions in order to judge the model's ability to produce  $O_3$  from the source emissions function. This is done with the knowledge that the initial ambient field did not in fact, contain clean

conditions. Surface and aircraft monitoring showed areas with higher  $O_3$  values, including the large  $O_3$  plume in the eastern Great Lakes area. Other plumes though, formed during the 2-day period, should be included in the simulation. Interpretation of model performance here must be done with this understanding of the potential omissions in the initial mass field. With this newly acquired appreciation of the effects of initial conditions all future simulations will begin at a clean period and proceed for one week or more in time. It was, however, still thought useful to analyze the results of this short test episode as an exercise in some of the model evaluation techniques that will be used in longer term simulations.

Boundary concentrations, both at the lateral edges and the top of the modeling region, are handled similarly to the initial concentrations for this 2-day episode. That is, tropospheric background values are used at all boundaries for all times. The combination of the clean initial and boundary concentrations here produced simulation results reflecting these clean concentrations, except where source emissions injections into the model domain raised the level of pollutants above background. The background tropospheric  $O_3$  concentration specified in ROM1 was around 40 ppb, and model results show this  $O_3$  value through large sections of the domain during the simulation. Actual ambient boundary layer  $O_3$  values of 60-80 ppb  $O_3$  were measured by most of the aircraft sampling performed during the 3-4 August period. Therefore there is an inherent underpredictive bias of 30-40 ppb of  $O_3$  introduced into this model simulation because of the inconsistency in background values. Future applications of the regional model will provide for day/night temporal variations in the lateral boundary concentrations.

### SECTION 3

#### RESULTS OF MODEL SIMULATION FOR $O_3$

The ROM1 model was run for the 48-hour period of 3-4 August 1979 using data from the NEROS and SAROAD data bases. Before the model itself was started the series of required preprocessors was run to provide the necessary model inputs to the ROM1 (Scherer and Fabrick, 1985). The model was initialized throughout its entire domain with a set of tropospheric background species concentrations which were computationally adjusted for chemical equilibrium. These concentrations are shown in Table 2. The same set of concentrations was used for both lateral inflow and top boundary concentrations throughout the model simulation period. These chemical species correspond to those in the 36 reaction Demerjian chemical kinetic mechanism contained in ROM1.

The evaluation of the ROM1 results here for  $O_3$  occurs in several stages. First we compare model predictions, interpolated to the surface SAROAD station locations, with observed values over all hours and receptor sites. The model predictions, which are available every 30 minutes, have been averaged into 1-hour intervals to correspond with the hourly averaged surface data. Next, an analysis of the maximum concentrations at receptor locations is made, and finally a close look at individual plumes from large source areas within the domain is performed. Aircraft observations of  $O_3$  concentrations in urban plumes, where available, are included in the analysis. We ignore the first 6 hours of predictions from the model because of the strong influence of initial conditions in this period. Therefore the first hour that comparisons of observed and predicted data are made is 0600-0700 h, LST on 3 August and the last hour of the evaluation period is 2300-2400 h, LST on 4 August.

#### Hourly Data Comparisons

Figure 9 presents a histogram of the hourly  $O_3$  values observed by the surface monitoring stations in the ROM1 domain during the model evaluation period. There is a pronounced peak in the observations at very low values of

TABLE 2. SET OF INITIAL AND BOUNDARY SPECIES  
CONCENTRATIONS USED IN ROM1

| Species          | Concentration<br>(ppb)   | Species                         | Concentration<br>(ppb)    |
|------------------|--------------------------|---------------------------------|---------------------------|
| NO               | .00658                   | H <sub>2</sub> O <sub>2</sub>   | .002571                   |
| NO <sub>2</sub>  | 1.824                    | O                               | 2.180 X 10 <sup>-9</sup>  |
| O <sub>3</sub>   | 36.9                     | NO <sub>3</sub>                 | .01345                    |
| olefins          | .3087                    | OH                              | 7.953 X 10 <sup>-6</sup>  |
| paraffins        | .3919                    | HO <sub>2</sub>                 | .003544                   |
| aldehydes        | .04323                   | HO <sub>2</sub> NO <sub>2</sub> | .002115                   |
| aromatics        | .1224                    | RO                              | 1.254 X 10 <sup>-9</sup>  |
| CO               | 99.98                    | RO <sub>2</sub>                 | .001722                   |
| HNO <sub>2</sub> | .001939                  | R <sub>2</sub> O                | 1.196 X 10 <sup>-10</sup> |
| HNO <sub>3</sub> | .1523                    | R <sub>1</sub> O <sub>2</sub>   | 7.089 X 10 <sup>-7</sup>  |
| PAN              | 4.931 X 10 <sup>-5</sup> | R <sub>2</sub> O <sub>2</sub>   | 1.526 X 10 <sup>-4</sup>  |
| RNO <sub>3</sub> | 1.803 X 10 <sup>-8</sup> |                                 |                           |

## OBSERVED OZONE

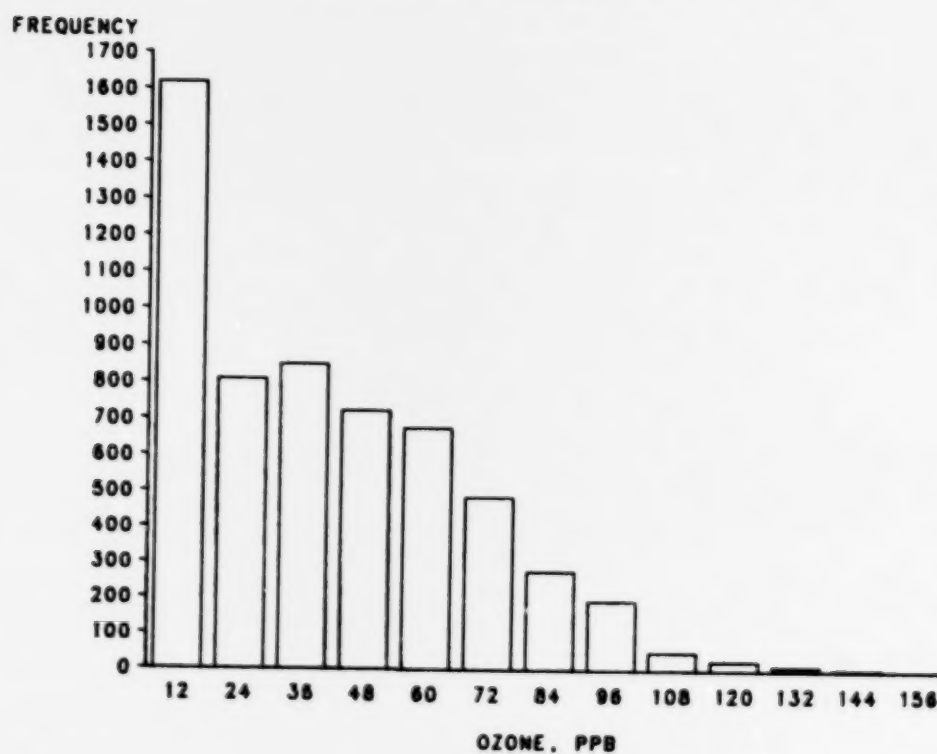


Figure 9. Histogram of observed  $O_3$  concentrations at surface monitoring sites on 3-4 August 1979.

O<sub>3</sub>, between 0 and 18 ppb. The magnitude of this peak might be confusing. These low values are generally occurring at night and are the result of near surface depletion of O<sub>3</sub> by ground deposition and chemical reaction. Instrument sensitivity at such low concentration levels must also come into question. Beyond these values, a broad peak in the distribution up to about 65 ppb is seen, beyond which the frequency distribution drops off gradually to the maximum values, near 160 ppb.

Figures 10a and 10b present the histograms of hourly predicted O<sub>3</sub> values interpolated to the surface monitoring site locations from the ROM1 layers 0 and 1, respectively. These distributions appear more normally-shaped (Gaussian) than the observed distribution and have sharp peaks in the 25-45 ppb vicinity. This concentration range spans the specified background value for O<sub>3</sub> of 37 ppb which is used by ROM1 for lateral and top boundary concentrations.

Apparently this background value dominates the ROM1 predictions at grid locations of the surface monitoring sites over many of the simulation hours. The peak in the layer 0 distribution appears in the 25-35 ppb range while the peak in layer 1 predictions is 35-45 ppb. This slight shift toward lower values in layer 0 reflects the effects of ground deposition and the sub-grid scale processes that chemically deplete O<sub>3</sub> in the surface layer. In general, the layer 0 ROM1 concentrations are a few ppb less than the corresponding layer 1 concentrations over the grid.

The residual or bias in the concentration predictions,  $d$ , is defined as the difference between the observed and predicted O<sub>3</sub> concentrations. That is, for layer 0,  $d_0 = c_{ob} - c_{p0}$ , and for layer 1,  $d_1 = c_{ob} - c_{p1}$ . The histograms of  $d_0$  and  $d_1$  for the model simulation period are shown respectively in Figures 11a and 11b. The peak value in both figures appears slightly on the negative, or overpredictive, side of the Gaussian shaped distributions. The negative peaks in these figures are artifacts of the model. These overpredicted concentrations correspond to very low ambient O<sub>3</sub> values observed mostly at night. The majority of surface monitoring stations are located in or near urban areas and are thus sensitive to rapid spatial or temporal changes in

## PREDICTED LAYER ZERO OZONE

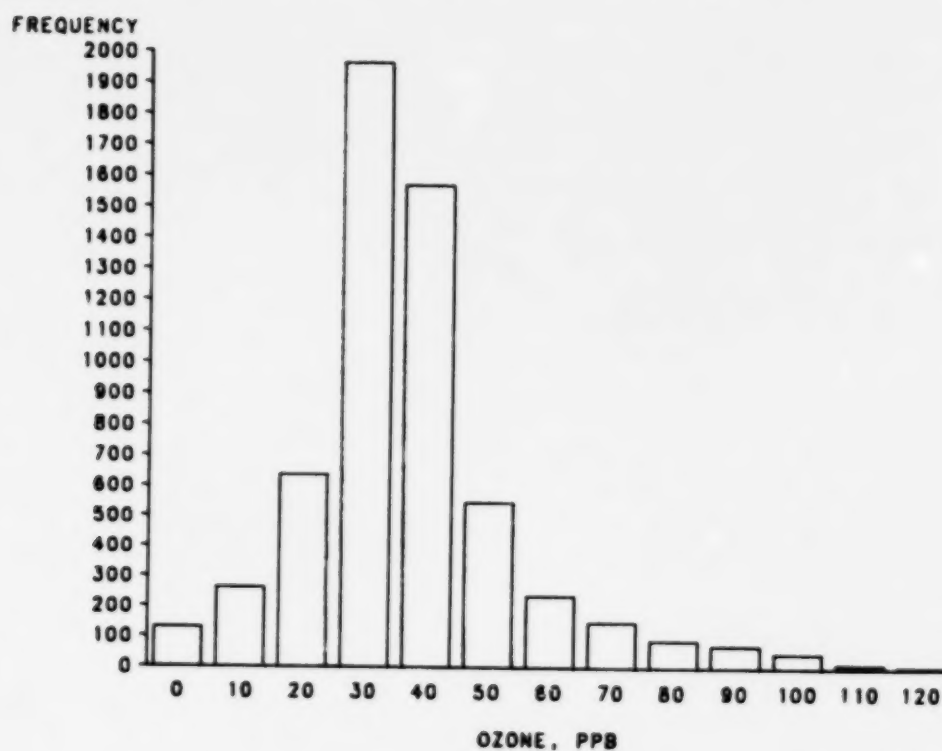


Figure 10a. Histogram of O<sub>3</sub> concentrations predicted by ROM1 at monitoring site locations for 3-4 August 1979 (ROM1 layer 0).

## PREDICTED LAYER ONE OZONE

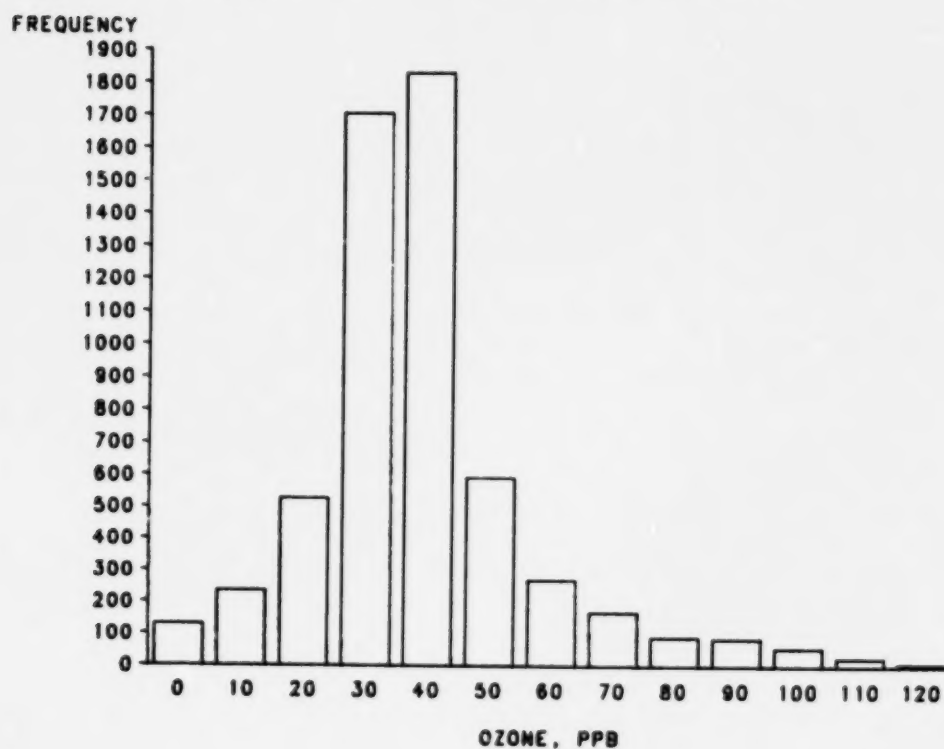


Figure 10b. Histogram of  $O_3$  concentrations predicted by ROM1 at monitoring site locations for 3-4 August 1979 (ROM1 layer 1).

## OBSERVED MINUS PREDICTED OZONE, LEVEL ZERO

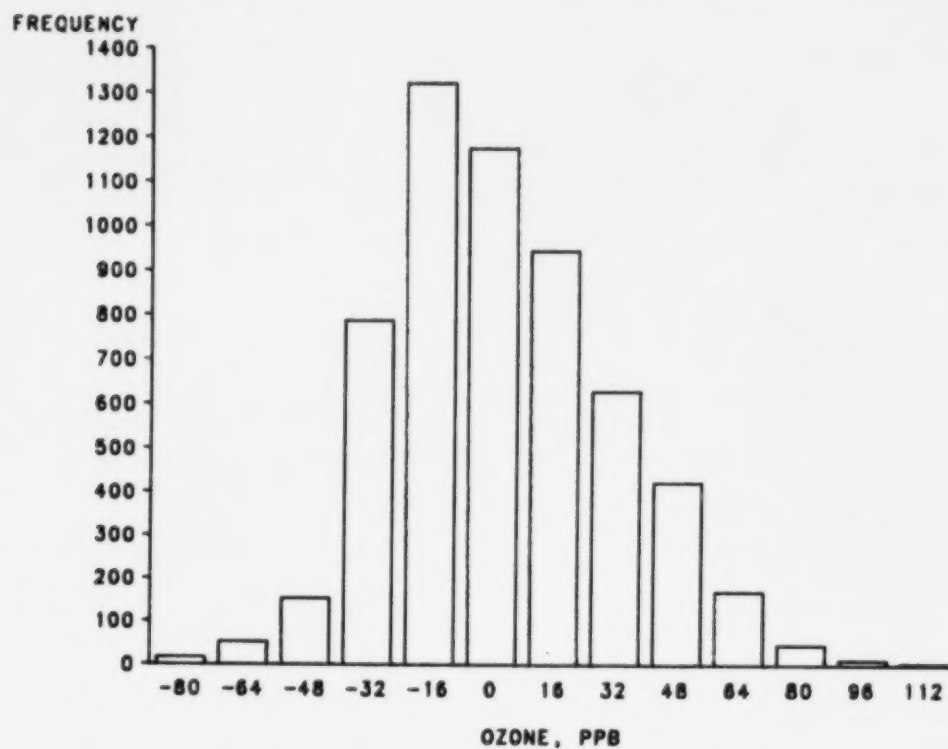


Figure 11a. Histogram of residual  $O_3$  concentrations at monitoring site locations for 3-4 August 1979, ROM1 layer 0.

## OBSERVED MINUS PREDICTED OZONE, LEVEL ONE

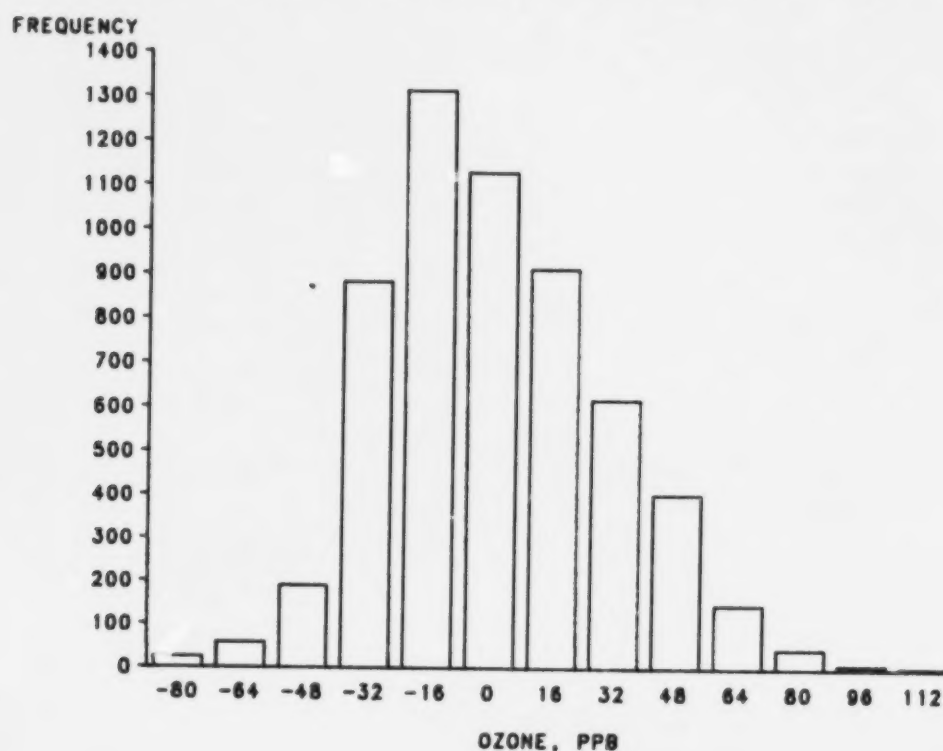


Figure 11b. Histogram of residual  $O_3$  concentrations at monitoring site locations for 3-4 August 1979, ROM1 layer 1.

emissions patterns, especially the titration of  $O_3$  by  $NO_x$  sources. On the other hand the ROM1 predictions are volumetric averages over the  $20\text{ km} \times 20\text{ km} \times H$  size of the grid cell (where  $H$  is the depth of the grid cell). Therefore, the sub-grid scale effects from urban area sources are typically only a small perturbation on the volumetric average predicted cell concentration. This will lead to overprediction under these circumstances and is reflected in the negative peak in the histograms. The majority of daytime residuals corresponds to underpredictions and we speculate at this point that they would be aligned with higher  $O_3$  concentrations. A discussion of the trends in magnitude of the bias with ambient concentration level is given later in the discussion of concentration maxima.

The average bias in layer 0  $O_3$  predictions over all surface monitoring locations is shown in Figure 12a as a function of time. The first data point, at 6 hours after the start of model simulation, corresponds to the hour period 06-07 h, LST on 3 August 1979. The 95% confidence interval about each average bias point is also shown. Figure 12b presents the same information, except as the percent bias of the observed  $O_3$  concentration. Figure 12c is another way of showing this information in a time series. It is a box plot of the bias among the surface monitoring locations where the middle of each box is the median, the top edge is the 75th percentile, the bottom edge is the 25th percentile, and the minimum and maximum points are the bottom and top, respectively, of the vertical projections from the box. All three time series show a distinct diurnal trend in the average bias, with underpredictions averaging 30-32% during the midday hours and overpredictions averaging as much as 100+ % at night. These large overpredictions correspond to relatively modest bias values, 10 to 25 ppb, as seen from Figure 12a. At those times of high overpredictions, the bias and percent bias figures imply observed and predicted  $O_3$  values on the order of 20 and 40 ppb, respectively, confirming an earlier premise made from analyzing the histograms that the ROM1 overpredictions correspond to quite low ambient concentrations.

From Figure 12c it is seen that the median underpredictions on the first day of simulation peak at about 20 ppb and on the second day at nearly 30 ppb,

## BIAS AVERAGE ALL RECEPTORS, LAYER ZERO

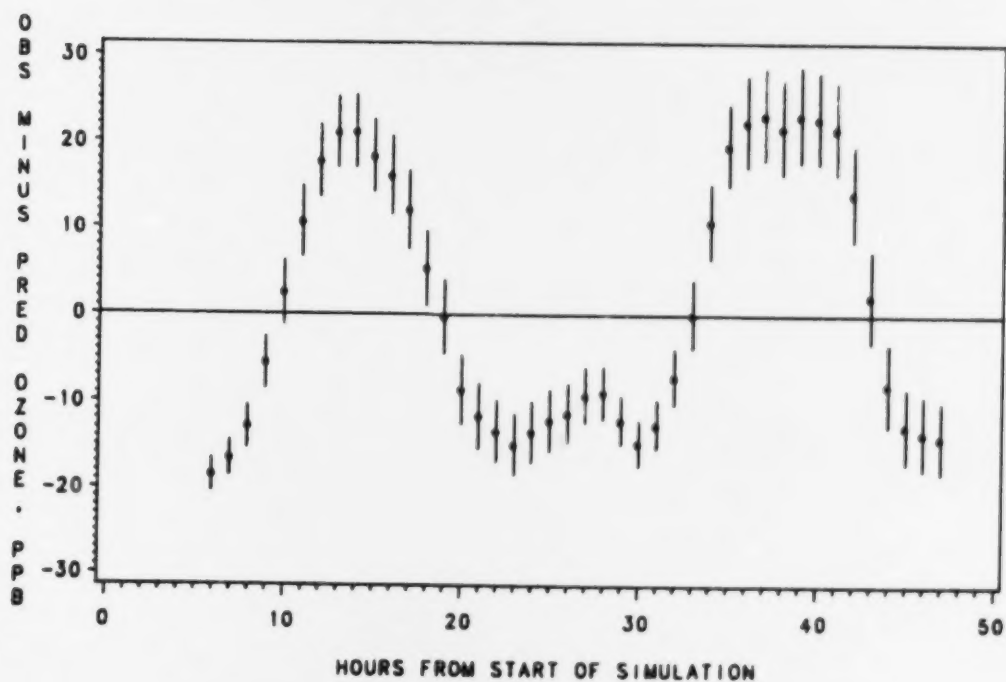


Figure 12a. Time-series over the 3-4 August 1979 simulation period of average bias over all surface receptor locations.

## PERCENT BIAS AVERAGE ALL RECEPTORS, LAYER ZERO

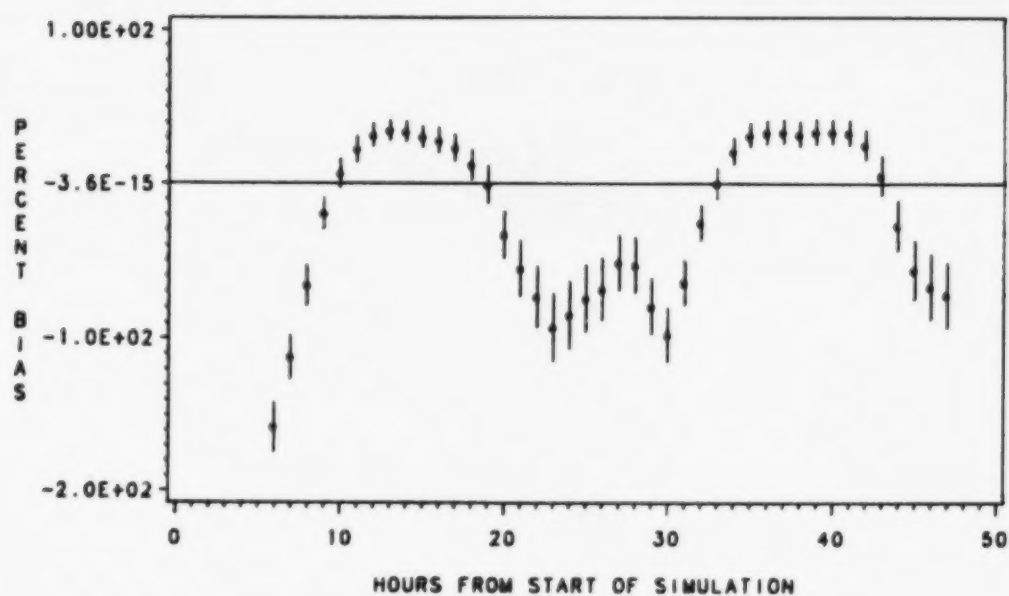


Figure 12b. Time-series over the 3-4 August 1979 simulation period of average percent bias over all surface receptor locations.

## BIAS ALL RECEPTORS, LAYER ZERO

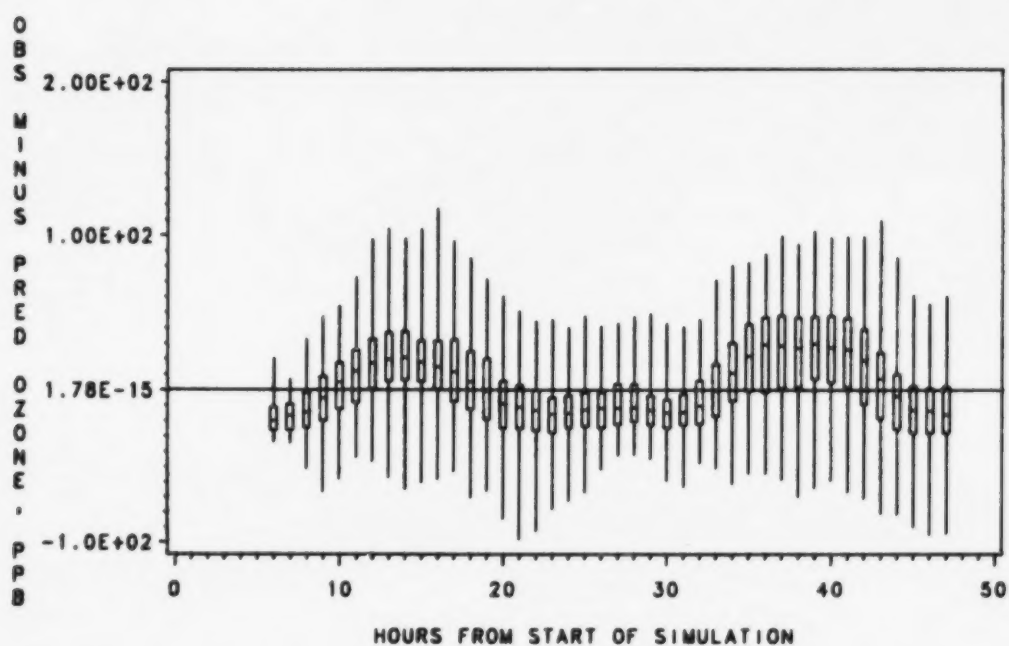


Figure 12c. Time-series over the 3-4 August 1979 simulation period of a box-plot distribution of bias over all surface receptor locations.

both during the daylight hours when  $O_3$  is expected to reach its daily maximum values. Taken together with the percent underpredictions these bias values imply that the  $O_3$  observations during the midday period on 3 August at the monitoring site locations are in the 60-65 ppb range, while the layer 0 predictions are in the 40-45 ppb range. On 4 August the corresponding observed and predicted ranges are 65-70 ppb and 40-45 ppb, respectively. The layer 0 predictions are at a level generally near the specified background and initial  $O_3$  concentrations, indicating their influence over the grid locations corresponding to the surface monitoring sites. It should be reiterated here that the surface monitoring sites are not regularly spaced in the NEROS region, but are concentrated near urban areas. The underprediction during this period may be the result of the model's inability to correctly replicate all of the sub-grid processes, transport inaccuracies, or other problems. A closer look at some specific areas of the grid will be examined later. Figure 12a indicates that there are only four hours during the simulation period when the average bias is not significantly different from zero. These hours occur during transitional time periods on both days of simulation. Although not shown here, the corresponding time series plots from RUM1 layer 1 results are very similar to those discussed for layer 0.

A tabulation of hourly averaged parameters for the simulation period is given in Table 3. Parameter abbreviations are defined in the Glossary and their significance is discussed in Schere and Fabrick (1985). For each hour displayed there are 'n' monitoring station locations used in the averages. The values in the table confirm the very low observed  $O_3$  concentrations at night. The diurnal range in  $O_3$  concentrations is considerably greater in the observations than in the model predictions, where a variation of only 10-15 ppb is shown. The bias values confirm the data presented in Figure 12 with negative values at night and positive values during the day. The absolute values of bias (gross error) are all consistently rather high, indicating that the hours with average bias near zero actually contain a wide variation of individual values with opposite signs. The episodic average value of observed  $O_3$  for all hours at the surface monitoring sites was 38.9 ppb and the corresponding model predictions for RUM1 layers 0 and 1 were 36.6 and 38.1 ppb,

TABLE 3. SUMMARY OF ROM1 HOURLY RESULTS FOR 3-4 AUGUST 1979

| DATE - HOUR | n   | $R_{c_{ob}}$ | $R_{c_{p0}}$ | $R_{c_{p1}}$ | $R_{d0}$ | $R_{ d0 }$ | $R_{S_{d0}}$ | $R_{d1}$ | $R_{ d1 }$ | $R_{S_{d1}}$ |
|-------------|-----|--------------|--------------|--------------|----------|------------|--------------|----------|------------|--------------|
|             |     | (ppb)        | (ppb)        | (ppb)        | (ppb)    | (ppb)      | (ppb)        | (ppb)    | (ppb)      | (ppb)        |
| 79215 06    | 111 | 11.6         | 30.0         | 32.0         | -18.4    | 19.0       | 10.1         | -20.3    | 20.9       | 10.5         |
| 07          | 110 | 14.6         | 31.1         | 32.5         | -16.4    | 17.1       | 10.7         | -17.8    | 18.4       | 11.0         |
| 08          | 134 | 19.4         | 32.2         | 33.5         | -12.8    | 15.9       | 14.2         | -14.2    | 17.0       | 14.4         |
| 09          | 140 | 28.4         | 33.8         | 35.2         | - 5.5    | 15.0       | 17.6         | - 6.8    | 15.2       | 17.6         |
| 10          | 142 | 38.0         | 35.5         | 37.0         | 2.6      | 17.8       | 21.8         | 1.0      | 17.6       | 21.8         |
| 11          | 144 | 47.8         | 37.1         | 38.5         | 10.7     | 21.6       | 24.6         | 9.3      | 21.1       | 24.6         |
| 12          | 148 | 56.4         | 38.6         | 40.1         | 17.6     | 24.8       | 25.5         | 16.3     | 24.3       | 25.6         |
| 13          | 147 | 61.3         | 40.2         | 41.6         | 21.1     | 25.8       | 25.0         | 19.7     | 25.1       | 25.1         |
| 14          | 148 | 62.8         | 41.6         | 43.0         | 21.2     | 26.6       | 25.7         | 19.8     | 25.8       | 25.8         |
| 15          | 150 | 60.1         | 41.8         | 43.0         | 18.3     | 25.0       | 25.5         | 17.1     | 24.3       | 25.8         |
| 16          | 149 | 57.0         | 40.9         | 42.8         | 16.1     | 25.0       | 27.7         | 14.1     | 24.2       | 27.9         |
| 17          | 150 | 52.4         | 40.2         | 41.9         | 12.1     | 24.1       | 27.7         | 10.5     | 23.9       | 28.0         |
| 18          | 148 | 44.1         | 38.7         | 40.3         | 5.3      | 21.2       | 26.1         | 3.7      | 21.1       | 26.4         |
| 19          | 145 | 35.4         | 35.6         | 37.6         | - 0.2    | 20.7       | 25.5         | - 2.1    | 21.2       | 25.9         |
| 20          | 142 | 25.7         | 34.2         | 35.4         | - 8.5    | 20.0       | 23.5         | - 9.8    | 20.7       | 23.8         |
| 21          | 133 | 20.9         | 32.4         | 33.8         | -11.5    | 19.5       | 21.8         | -12.9    | 20.4       | 22.1         |
| 22          | 126 | 18.1         | 31.4         | 32.9         | -13.3    | 19.1       | 19.8         | -14.8    | 20.2       | 20.5         |
| 23          | 122 | 15.9         | 30.7         | 31.9         | -14.8    | 20.1       | 19.1         | -16.0    | 21.1       | 19.5         |
| 79216 00    | 114 | 15.7         | 29.1         | 30.5         | -13.4    | 19.2       | 18.2         | -14.8    | 20.1       | 18.8         |
| 01          | 114 | 16.2         | 28.2         | 29.4         | -12.0    | 18.5       | 18.6         | -13.3    | 19.4       | 19.1         |

TABLE 3. (continued)

| DATE - HOUR | n   | $R_{C_{ob}}$ | $R_{C_{p0}}$ | $R_{C_{p1}}$ | $R_{d0}$ | $R_{ d_0 }$ | $R_{S_{d0}}$ | $R_{d1}$ | $R_{ d_1 }$ | $R_{S_{d1}}$ |
|-------------|-----|--------------|--------------|--------------|----------|-------------|--------------|----------|-------------|--------------|
|             |     | (ppb)        | (ppb)        | (ppb)        | (ppb)    | (ppb)       | (ppb)        | (ppb)    | (ppb)       | (ppb)        |
| 02          | 114 | 16.4         | 27.6         | 28.8         | -11.2    | 17.6        | 17.6         | -12.4    | 18.6        | 18.1         |
| 03          | 121 | 17.8         | 27.0         | 28.1         | - 9.2    | 16.8        | 17.6         | -10.3    | 17.6        | 18.0         |
| 04          | 129 | 16.7         | 25.6         | 27.0         | - 8.9    | 16.2        | 16.9         | -10.3    | 17.1        | 17.4         |
| 05          | 121 | 15.1         | 27.2         | 28.5         | -12.1    | 16.2        | 14.9         | -13.4    | 17.2        | 15.5         |
| 06          | 129 | 15.0         | 29.7         | 31.9         | -14.7    | 17.5        | 14.9         | -16.9    | 19.5        | 16.2         |
| 07          | 137 | 19.5         | 32.1         | 34.0         | -12.6    | 17.0        | 16.2         | -14.5    | 18.6        | 17.3         |
| 08          | 150 | 27.7         | 34.8         | 36.5         | - 7.1    | 17.0        | 19.1         | - 8.8    | 18.0        | 20.0         |
| 09          | 140 | 38.1         | 38.1         | 39.5         | 0.0      | 18.8        | 23.0         | - 1.4    | 19.2        | 23.4         |
| 10          | 143 | 51.6         | 40.9         | 42.4         | 10.8     | 22.5        | 26.0         | 9.2      | 22.3        | 26.3         |
| 11          | 144 | 62.5         | 42.9         | 44.4         | 19.6     | 28.6        | 28.3         | 18.1     | 28.1        | 28.6         |
| 12          | 135 | 67.5         | 45.1         | 46.7         | 22.4     | 32.4        | 30.3         | 20.8     | 31.9        | 30.6         |
| 13          | 142 | 68.9         | 45.7         | 47.4         | 23.2     | 33.6        | 31.7         | 21.5     | 33.0        | 32.0         |
| 14          | 144 | 67.6         | 45.9         | 47.5         | 21.7     | 33.5        | 32.4         | 20.1     | 33.1        | 32.8         |
| 15          | 142 | 68.7         | 45.5         | 47.4         | 23.2     | 34.4        | 32.6         | 21.3     | 33.7        | 33.0         |
| 16          | 148 | 67.7         | 44.9         | 46.7         | 22.8     | 33.4        | 32.2         | 21.1     | 32.8        | 32.6         |
| 17          | 150 | 65.4         | 43.8         | 45.3         | 21.6     | 32.9        | 32.7         | 20.0     | 32.3        | 33.0         |
| 18          | 149 | 55.8         | 41.8         | 43.5         | 14.0     | 30.0        | 33.2         | 12.3     | 29.6        | 33.4         |
| 19          | 148 | 40.9         | 38.8         | 41.1         | 2.2      | 25.4        | 31.9         | - 0.1    | 25.0        | 31.8         |
| 20          | 142 | 29.3         | 37.3         | 38.9         | - 8.0    | 21.9        | 27.9         | - 9.5    | 22.5        | 28.4         |
| 21          | 137 | 22.7         | 35.3         | 36.9         | -12.7    | 22.4        | 25.1         | -14.3    | 23.3        | 25.7         |

TABLE 3. (continued)

| DATE - HOUR     | n   | $\bar{R}_{c_{ob}}$ | $\bar{R}_{c_{p0}}$ | $\bar{R}_{c_{p1}}$ | $\bar{R}_{d0}$ | $\bar{R}_{d0}$ | $R_{S_{d0}}$ | $\bar{R}_{d1}$ | $\bar{R}_{d1}$ | $R_{S_{d1}}$ |      |
|-----------------|-----|--------------------|--------------------|--------------------|----------------|----------------|--------------|----------------|----------------|--------------|------|
|                 |     | (ppb)              | (ppb)              | (ppb)              | (ppb)          | (ppb)          | (ppb)        | (ppb)          | (ppb)          | (ppb)        |      |
| 22              | 128 | 20.2               | 33.6               | 35.0               | -13.5          | 22.0           | 24.0         | -14.8          | 22.8           | 24.4         |      |
| 23              | 118 | 19.4               | 33.4               | 34.5               | -14.0          | 20.7           | 22.2         | -15.1          | 21.5           | 22.6         |      |
| 79215           | ALL | 2489               | 38.6               | 36.2               | 37.7           | 2.4            | 21.2         | 26.5           | 0.9            | 21.4         | 26.7 |
| 79216           | ALL | 3239               | 39.2               | 36.9               | 38.5           | 2.3            | 24.0         | 29.8           | 0.7            | 24.4         | 30.1 |
| 79215-<br>79216 | ALL | 5728               | 38.9               | 36.6               | 38.1           | 2.3            | 22.8         | 28.4           | 0.8            | 23.1         | 28.7 |

respectively. These values represent a 5.9% underprediction for layer 0 and a 2.1% underprediction for layer 1. Since these average O<sub>3</sub> levels are near tropospheric background values the significance of this analysis over all hourly values in the simulation period is not particularly great.

The next step was to perform an hourly analysis with a subset of the data values already used. The criterion for choosing the subset was based, in part, on the tropospheric background value of near 40 ppb O<sub>3</sub> used in the ROM1's initial and boundary conditions and the fact that many of the surface monitoring site locations showed O<sub>3</sub> predictions near this value. Therefore the data subset is based on only those receptor points where the observed value and the level 0 and 1 predicted values of O<sub>3</sub> are greater than 50 ppb. This should limit the data to those sites most affected by source emissions within the NERUS region. In fact the number of sites used in the analysis dropped from near 150 during the midday hours to around 30, and from around 120 during the nighttime hours to 0, after this criterion was applied.

The choice of criterion for the data subset might not seem to be the most obvious at first. Perhaps a more logical subset would be formed from choosing all points where only the observed O<sub>3</sub> concentration was greater than 50 ppb. In practice, this was the first subset produced for the analysis. It was found that this subset still contained far too many model predictions near tropospheric background levels to be useful in the restricted subset analysis. A number of factors could account for this including error in the location of source plumes within the model domain through transport uncertainty or source emission uncertainties. The overriding factor however is the assumption of tropospheric O<sub>3</sub> concentration values everywhere at the boundaries and initially when, in fact, areas of higher O<sub>3</sub> concentrations were observed. In any case the more restrictive criterion that was ultimately chosen produced the desired effect of reducing the data subset to those concentration values above the level of tropospheric background O<sub>3</sub>, and presumably produced data points more affected by local and transported photochemical effects.

The histogram of observed  $O_3$  concentrations in this data subset is presented in Figure 13. The concentration values along the axis of the plot are midpoints of the range for each class. The distribution peaks in the range 55-65 ppb and then falls off rapidly. The distribution slowly diminishes in the range above 75 ppb. This distribution does not contain the broad plateau of lower values of  $O_3$  shown in Figure 9 for the full data set. The effect of eliminating the low data values is apparent in comparing the two figures. The reason for the lower maximum value in the data subset histogram is that we have screened out data points where either the observed or predicted values are less than 50 ppb. Thus the station that observed nearly 160 ppb showed a corresponding prediction of less than 50 ppb and was not included in the data subset.

Figures 14a and 14b present the histograms of the ROM1  $O_3$  predictions for layers 0 and 1, respectively, for the data subset. The predictions are skewed toward the lower end of the concentration range in the data subset. The number of model predictions above about 65 ppb is markedly lower, although the higher values extend to the 120 - 130 ppb range, nearly matching that on the observed concentration histogram. Comparing these histograms with those for the full set shown in Figure 10, it can be seen that the large number of predictions near the tropospheric background  $O_3$  value are now eliminated, although the effect of this background value still persists to some extent in the peak for the range of 50-60 ppb of the data subset.

Histograms of  $d_0$  and  $d_1$  on the data subset are shown in Figures 15a and 15b. These distributions are Gaussian shaped with a peak at the zero range residual. In general, both layers 0 and 1 residuals are symmetrically distributed except for the larger tail on the underpredictive side. These histograms show a similar distribution to those in Figure 11 for the full data set, except they are not as asymmetrical as those in the latter figure.

## OBSERVED OZONE

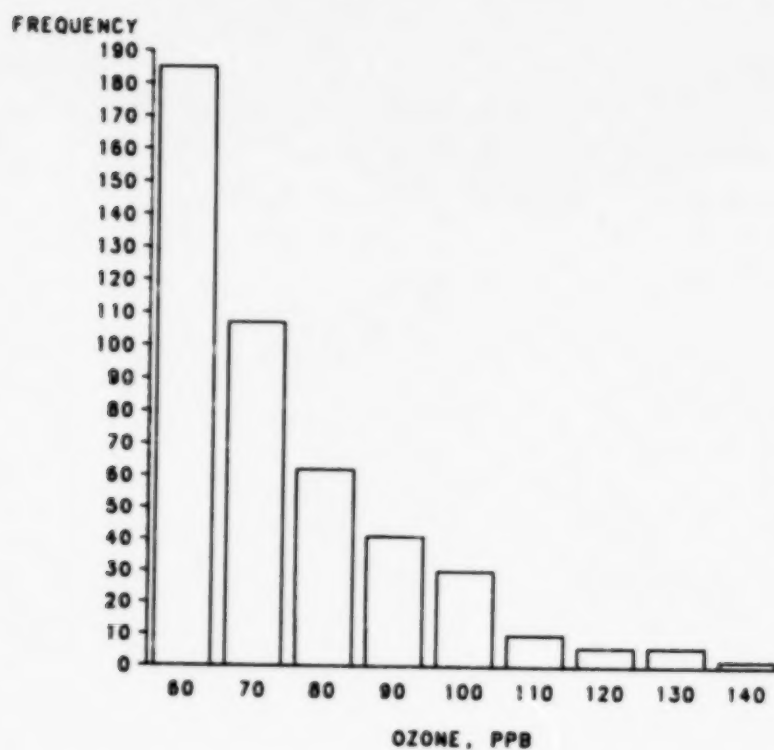


Figure 13. Histogram of observed  $O_3$  concentrations at surface monitoring sites (where obs. and pred.  $O_3 > 50$  ppb) on 3-4 August 1979.

## PREDICTED LAYER ZERO OZONE

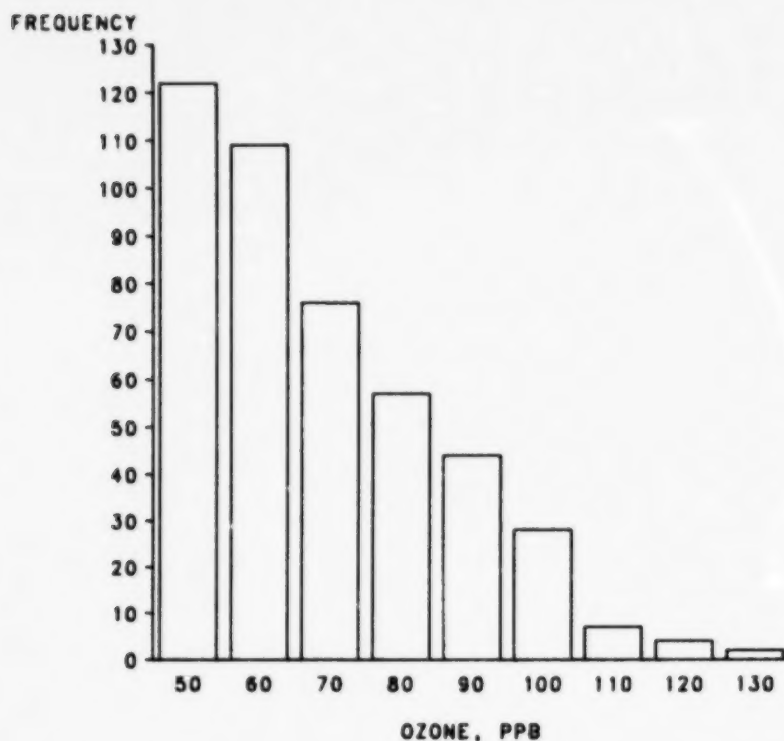


Figure 14a. Histogram of O<sub>3</sub> concentrations predicted by ROM1 at monitoring site locations (where obs. and pred. O<sub>3</sub> > 50 ppb) for 3-4 August 1979 (ROM1 layer<sup>3</sup>0).

## PREDICTED LAYER ONE OZONE

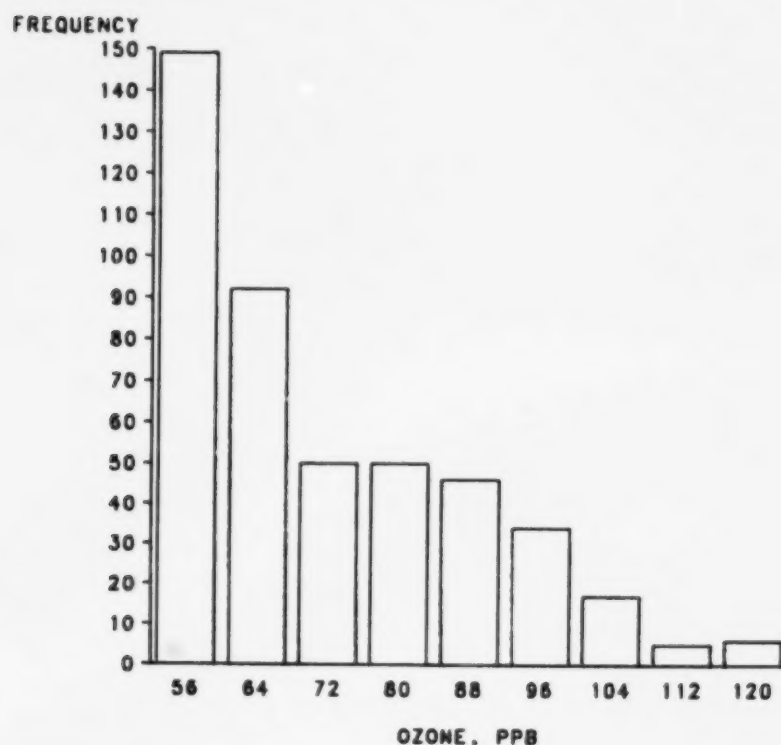


Figure 14b. Histogram of  $O_3$  concentrations predicted by ROM1 at monitoring site locations (where obs. and pred.  $O_3 > 50$  ppb) for 3-4 August 1979 (ROM1 layer<sup>3</sup>1).

## OBSERVED MINUS PREDICTED OZONE, LEVEL ZERO

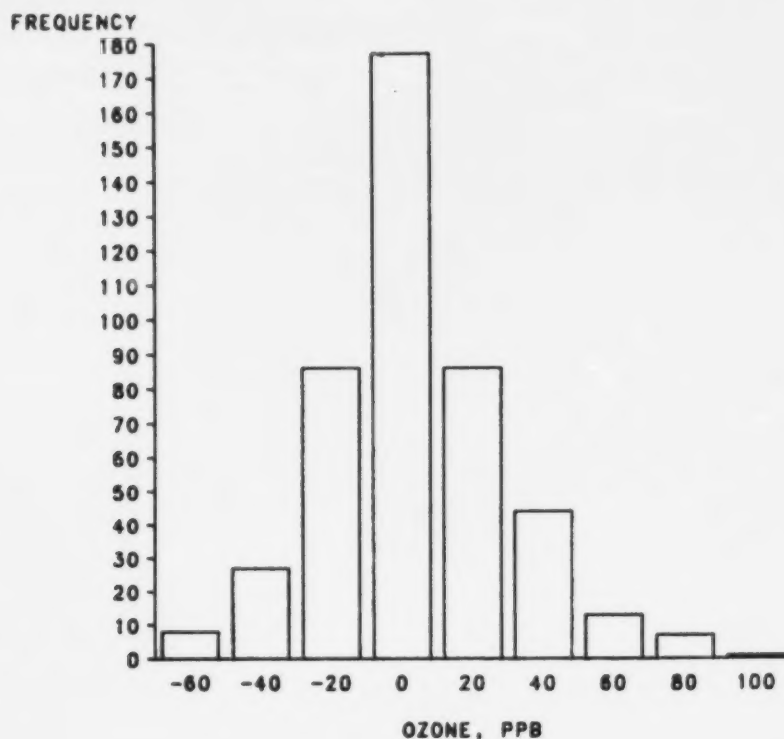


Figure 15a. Histogram of residual  $O_3$  concentrations at monitoring site locations (where obs. and pred.  $O_3 > 50$  ppb) for 3-4 August 1979 (ROM1 layer 0).

## OBSERVED MINUS PREDICTED OZONE, LEVEL ONE

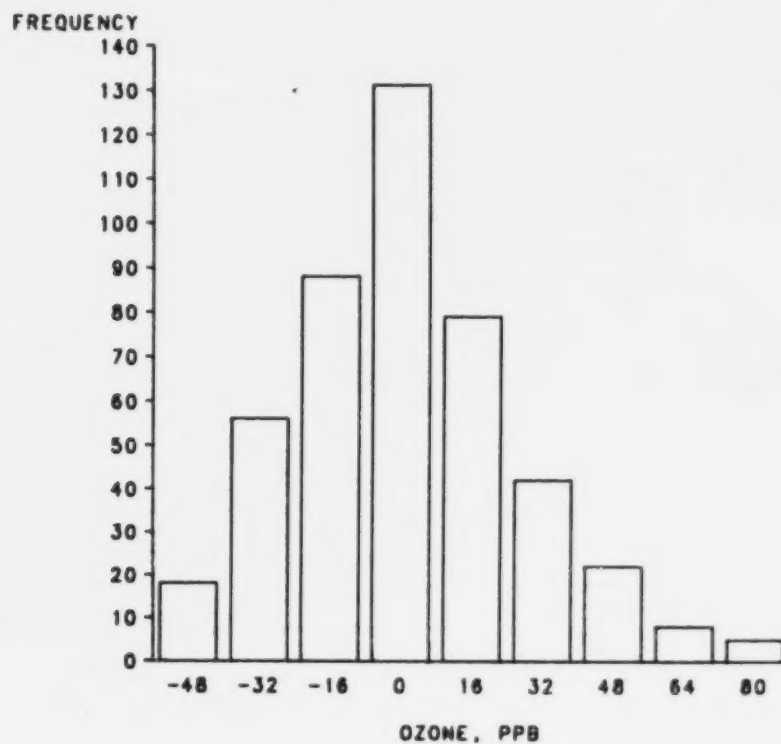


Figure 15b. Histogram of residual  $O_3$  concentrations at monitoring site locations (where obs. and pred.  $O_3 > 50$  ppb) for 3-4 August 1979 (ROM1 layer 1).

Plots of the time series of the concentration bias at the surface monitoring sites in the data subset are shown in Figure 16. The bias is depicted in Figure 16a and the percent bias in Figure 16b, with the 95% confidence interval about each point. It is immediately obvious that at certain hours there is little, if any, data in the subset being analyzed. This effect is a result of the elimination of the low O<sub>3</sub> values in this data subset, most of which occur during the nighttime hours. The diurnal variation in the bias for the full data set, seen in Figure 12, is also evident for the data subset in Figure 16. There are some irregularities in the periodicity but these are near the transition times when few data values have gone into the average. The hours with underpredictions are again generally during the daytime and the hours with overpredictions are during transitional periods or at night. These latter hours however, contain very few stations with observed or predicted concentrations above 50 ppb, so the significance of their bias value is not great. The largest values of average bias shown here are about 19% underpredicted at 1300 h on 3 August, and 14% underpredicted at 1500 h on 4 August. The magnitudes of these average bias values are fairly similar for both days of simulation. Although the plots are not shown here, the time series of bias in ROM1 layer 1 for the data subset are very similar to those shown for layer 0.

Table 4 presents a tabulation of hourly averaged parameters for values in the data subset. The number of surface monitoring sites at any given hour is considerably less here than in the full data set presented in Table 3. The maximum at any hour is 38 stations, as compared to 150 in the full set. The average observed concentration at the receptor locations varies from 51.0 ppb at 2000 h to 78.0 ppb at 1300 h on 3 August, and from 50.0 ppb at 0400 h and 0800 h to 80.7 ppb at 1600 h on 4 August. The corresponding predictions for layer 0 range from 56.0 ppb at 1900 h to 70.4 ppb at 1600 h on 3 August, and from 54.4 ppb at 0400 h to 76.2 ppb at 2000 h on 4 August. The episodic average value of observed O<sub>3</sub> in the data subset for all hours was 72.2 ppb and the corresponding ROM1 predictions for layers 0 and 1 were 68.9 and 71.2 ppb, respectively. This represents an average O<sub>3</sub> underprediction of 4.6% for ROM1 layer 0 and 1.4% for layer 1, a slightly smaller degree of underpre-

## BIAS AVERAGE ALL RECEPTORS, LAYER ZERO

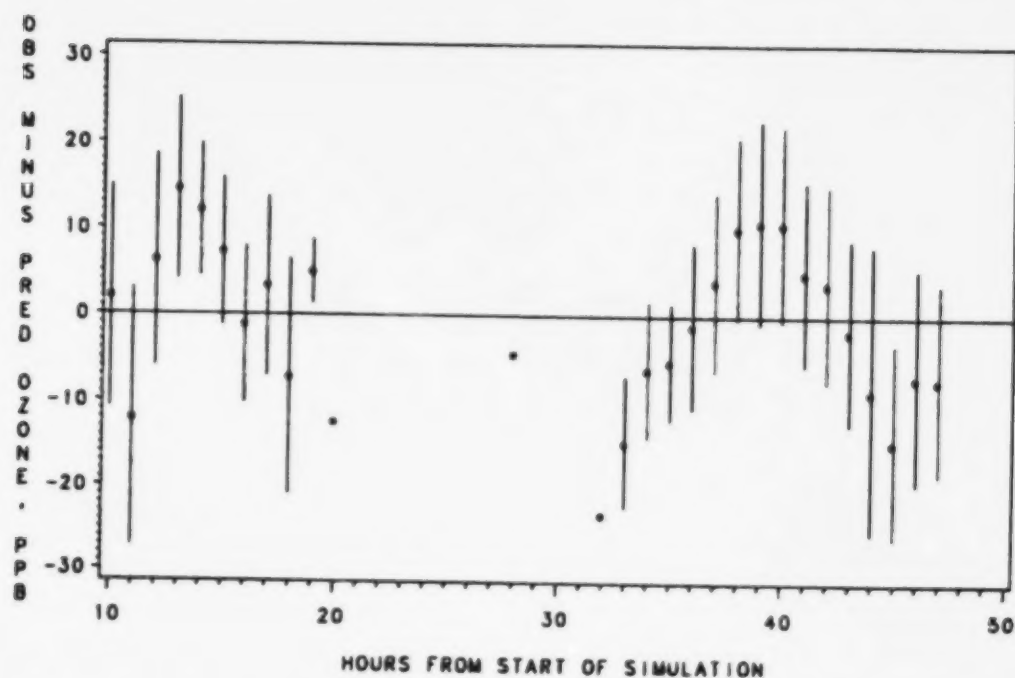


Figure 16a. Time-series over the 3-4 August 1979 simulation period of average bias over all surface receptor locations (where obs. and. pred.  $O_3 > 50$  ppb).

## PERCENT BIAS AVERAGE ALL RECEPTORS, LAYER ZERO

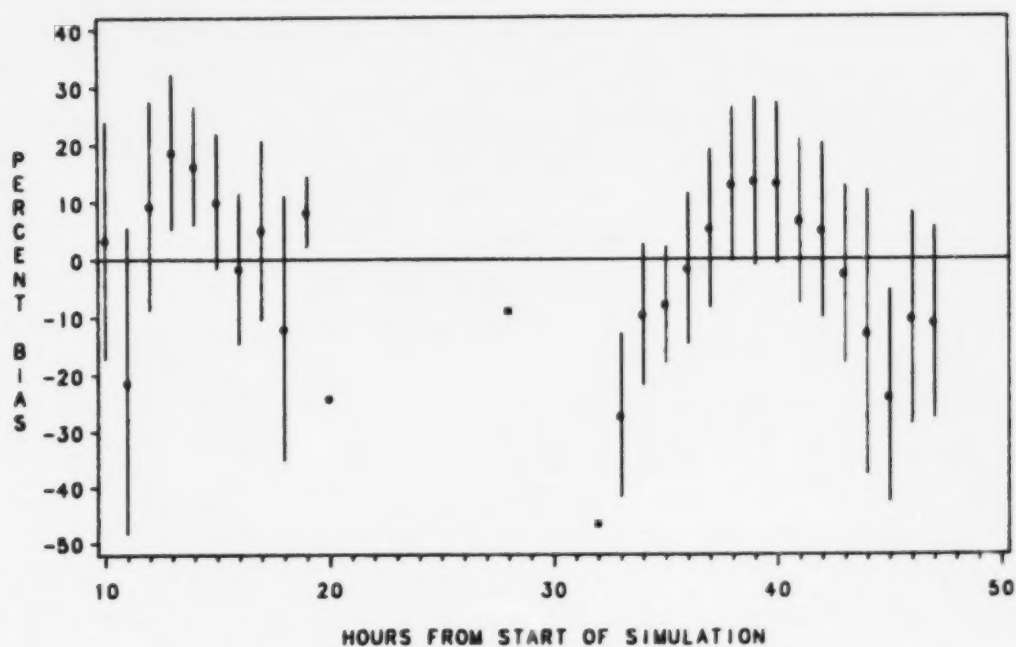


Figure 16b. Time-series over the 3-4 August 1979 simulation period of average percent bias over all surface receptor locations (where obs. and pred.  $O_3 > 50$  ppb).

TABLE 4. SUMMARY OF ROM1 HOURLY RESULTS FOR 3-4 AUGUST 1979 WHERE  
OBSERVED AND PREDICTED  $O_3 > 50$  PPB.

| DATE - HOUR | n  | $R_{c_{ob}}$ | $R_{c_{p0}}$ | $R_{c_{p1}}$ | $R_{d0}$ | $R_{ d_0 }$ | $R_{S_{d0}}$ | $R_{d1}$ | $R_{ d_1 }$ | $R_{S_{d1}}$ |
|-------------|----|--------------|--------------|--------------|----------|-------------|--------------|----------|-------------|--------------|
|             |    | (ppb)        | (ppb)        | (ppb)        | (ppb)    | (ppb)       | (ppb)        | (ppb)    | (ppb)       | (ppb)        |
| 79215 06    | 0  | -            | -            | -            | -        | -           | -            | -        | -           | -            |
| 07          | 0  | -            | -            | -            | -        | -           | -            | -        | -           | -            |
| 08          | 0  | -            | -            | -            | -        | -           | -            | -        | -           | -            |
| 09          | 0  | -            | -            | -            | -        | -           | -            | -        | -           | -            |
| 10          | 5  | 62.2         | 60.0         | 61.5         | 2.2      | 9.5         | 14.3         | 0.7      | 9.9         | 15.0         |
| 11          | 6  | 56.2         | 68.1         | 69.4         | -12.0    | 19.2        | 18.5         | -13.2    | 20.4        | 18.6         |
| 12          | 13 | 67.5         | 61.1         | 63.4         | 6.4      | 16.5        | 22.0         | 4.1      | 16.1        | 22.1         |
| 13          | 21 | 78.0         | 63.3         | 65.4         | 14.7     | 21.6        | 24.1         | 12.6     | 21.6        | 24.8         |
| 14          | 29 | 74.4         | 62.2         | 64.5         | 12.2     | 19.0        | 20.6         | 9.9      | 18.2        | 20.8         |
| 15          | 24 | 73.0         | 65.6         | 67.4         | 7.4      | 17.8        | 20.9         | 5.6      | 17.3        | 21.2         |
| 16          | 16 | 69.4         | 70.4         | 73.1         | - 1.0    | 13.7        | 18.1         | - 3.7    | 14.1        | 18.2         |
| 17          | 13 | 66.7         | 63.3         | 65.9         | 3.5      | 12.6        | 18.7         | 0.7      | 12.8        | 19.1         |
| 18          | 8  | 59.4         | 66.5         | 68.4         | - 7.1    | 16.1        | 19.3         | - 9.0    | 16.2        | 18.8         |
| 19          | 2  | 61.0         | 56.0         | 58.9         | 5.1      | 5.1         | 2.6          | 2.1      | 2.1         | 0.6          |
| 20          | 1  | 51.0         | 63.3         | 65.8         | -12.3    | 12.3        | -            | -14.8    | 14.8        | -            |
| 21          | 0  | -            | -            | -            | -        | -           | -            | -        | -           | -            |
| 22          | 0  | -            | -            | -            | -        | -           | -            | -        | -           | -            |
| 23          | 0  | -            | -            | -            | -        | -           | -            | -        | -           | -            |
| 79216 00    | 0  | -            | -            | -            | -        | -           | -            | -        | -           | -            |
| 01          | 0  | -            | -            | -            | -        | -           | -            | -        | -           | -            |

TABLE 4. (continued)

| DATE - HOUR | n  | $\bar{R}_{c_{ob}}$ | $\bar{R}_{c_{p0}}$ | $\bar{R}_{c_{p1}}$ | $\bar{R}_{d0}$ | $\bar{R}_{ d0 }$ | $\bar{R}_{S_{d0}}$ | $\bar{R}_{d1}$ | $\bar{R}_{ d1 }$ | $\bar{R}_{S_{d1}}$ |
|-------------|----|--------------------|--------------------|--------------------|----------------|------------------|--------------------|----------------|------------------|--------------------|
|             |    | (ppb)              | (ppb)              | (ppb)              | (ppb)          | (ppb)            | (ppb)              | (ppb)          | (ppb)            | (ppb)              |
| 02          | 0  | -                  | -                  | -                  | -              | -                | -                  | -              | -                | -                  |
| 03          | 0  | -                  | -                  | -                  | -              | -                | -                  | -              | -                | -                  |
| 04          | 1  | 50.0               | 54.4               | 56.8               | - 4.4          | 4.4              | -                  | -6.8           | 6.8              | -                  |
| 05          | 0  | -                  | -                  | -                  | -              | -                | -                  | -              | -                | -                  |
| 06          | 0  | -                  | -                  | -                  | -              | -                | -                  | -              | -                | -                  |
| 07          | 0  | -                  | -                  | -                  | -              | -                | -                  | -              | -                | -                  |
| 08          | 1  | 50.0               | 73.2               | 85.9               | -23.2          | 23.2             | -                  | -35.9          | 35.9             | -                  |
| 09          | 8  | 53.7               | 68.3               | 72.2               | -14.6          | 14.6             | 10.9               | -18.5          | 18.5             | 12.3               |
| 10          | 19 | 64.1               | 70.2               | 72.5               | - 6.2          | 13.6             | 17.1               | - 8.4          | 15.0             | 17.4               |
| 11          | 29 | 66.9               | 72.2               | 74.3               | - 5.3          | 16.0             | 18.1               | - 7.3          | 16.5             | 18.0               |
| 12          | 32 | 72.9               | 74.1               | 76.1               | - 1.2          | 21.7             | 26.9               | - 3.2          | 22.4             | 26.9               |
| 13          | 38 | 75.1               | 71.0               | 73.5               | 4.0            | 23.8             | 31.7               | 1.6            | 23.8             | 31.3               |
| 14          | 37 | 78.0               | 67.9               | 70.3               | 10.1           | 26.0             | 31.8               | 7.8            | 25.7             | 31.7               |
| 15          | 32 | 80.4               | 69.5               | 72.9               | 10.9           | 27.4             | 33.2               | 7.6            | 26.6             | 33.1               |
| 16          | 31 | 80.7               | 70.0               | 72.7               | 10.7           | 23.8             | 31.2               | 8.0            | 22.7             | 31.0               |
| 17          | 27 | 74.6               | 69.6               | 72.0               | 5.0            | 18.8             | 27.5               | 2.7            | 18.5             | 27.7               |
| 18          | 18 | 75.1               | 71.3               | 74.0               | 3.8            | 19.6             | 24.0               | 1.1            | 20.0             | 24.4               |
| 19          | 12 | 69.6               | 71.3               | 74.1               | - 1.8          | 13.6             | 18.5               | - 4.6          | 13.4             | 17.9               |
| 20          | 6  | 67.5               | 76.2               | 77.2               | - 8.7          | 17.4             | 20.5               | - 9.8          | 17.6             | 20.1               |
| 21          | 8  | 61.0               | 75.5               | 77.1               | -14.6          | 16.8             | 16.1               | -16.1          | 17.6             | 15.7               |

TABLE 4. (continued)

| DATE - HOUR         | n   | $R_{c_{ob}}$ | $R_{c_{p0}}$ | $R_{c_{p1}}$ | $R_{d0}$ | $R_{ d0 }$ | $R_{S_{d0}}$ | $R_{d1}$ | $R_{ d1 }$ | $R_{S_{d1}}$ |
|---------------------|-----|--------------|--------------|--------------|----------|------------|--------------|----------|------------|--------------|
|                     |     | (ppb)        | (ppb)        | (ppb)        | (ppb)    | (ppb)      | (ppb)        | (ppb)    | (ppb)      | (ppb)        |
| 22                  | 5   | 68.0         | 74.9         | 76.1         | - 7.0    | 11.8       | 14.0         | - 8.1    | 12.0       | 13.7         |
| 23                  | 7   | 66.7         | 74.0         | 75.3         | - 7.3    | 13.0       | 14.6         | - 8.6    | 13.5       | 14.8         |
| 79215 ALL           | 138 | 70.3         | 64.3         | 66.4         | 6.0      | 17.0       | 21.1         | 3.9      | 16.8       | 21.3         |
| 79216 ALL           | 311 | 73.1         | 70.9         | 73.4         | 2.2      | 20.8       | 27.3         | - 0.3    | 20.9       | 27.2         |
| 79215-<br>79216 ALL | 449 | 72.2         | 68.9         | 71.2         | 3.4      | 19.6       | 25.6         | 1.0      | 19.6       | 25.6         |

diction than the values computed for the full data set. The average values in the data subset are however, significantly greater than the tropospheric background  $O_3$  value.

#### Maximum Values Analysis

The most significant parameter of interest for the air quality policy maker concerning ambient  $O_3$  is the daily hourly average maximum value observed at a monitoring station. This is the value which is used, among other measures, to determine the extent of source emissions controls needed for the  $O_3$  precursor species. The model evaluation for maximum  $O_3$  concentration takes place in two steps here. First, in the local maxima analysis model predictions of maximum hourly average  $O_3$  at surface monitoring site locations are compared with measured values at the sites. Second, in the global maxima analysis the concentration magnitudes and position of plumes of  $O_3$  within the NEROS region are compared in the RUMI predictions and in the observations at surface monitoring sites, to the extent that these sites can define such plumes. The global maxima analysis is necessary because small errors in the transport field can displace the predicted area of maximum  $O_3$  concentrations just a short distance from the observed field, and cause large apparent underpredictions in the local maxima analysis. If the reason for the underprediction can be traced to a shift in position of the predicted  $O_3$  plume from the observed plume, the problem could be corrected, in theory, by a more accurate description of the wind field. A model's ability to predict the correct maximum concentration, not necessarily at the right location, is the most important aspect in performance because the air quality standards apply only to the  $O_3$  concentration level.

The local daily maximum  $O_3$  concentration,  $c_{ob}^{max}$ , at a measuring site can be compared with the corresponding model prediction in two different ways. First, the predicted maximum at the site,  $c_{p0}^{max}$  for RUMI layer 0 or  $c_{p1}^{max}$  for RUMI layer 1, can be compared to  $c_{ob}^{max}$ . Second, a more restrictive measure matches the prediction occurring at the same hour

as the observed maximum, with the observed concentration ( $c_{p0}(h_{ob}^{max})$  vs.  $c_{ob}^{max}$  and  $c_{p1}(h_{ob}^{max})$  vs.  $c_{ob}^{max}$ ). Figure 17 presents a scatterplot of the daily ROM1 layer 0 maximum  $O_3$  concentrations vs. observations at the surface monitoring sites over the 2-day episode modeled. Figure 17a contains the plot of  $c_{p0}^{max}$  vs.  $c_{ob}^{max}$  and Figure 17b shows the plot of  $c_{p0}(h_{ob}^{max})$  vs.  $c_{ob}^{max}$ . There is considerable scatter in both plots with little evidence of a strong correlation or trend. In fact the computed correlation coefficient between  $c_{p0}^{max}$  and  $c_{ob}^{max}$  is 0.08 and that between  $c_{p0}(h_{ob}^{max})$  and  $c_{ob}^{max}$  is 0.00.

Looking more closely at the plots in Figure 17 it is obvious that a large cluster of the data points corresponds to an observed concentration range of 60-100 ppb and a predicted range of 30-50 ppb. These points correspond to receptor locations where the model has shown essentially only background  $O_3$  concentrations and the monitors have detected increased levels above background. This effect may be due to a misplaced plume location in the predictions or an underestimate of the effect from precursor emissions. The plots also show a wide scatter in the data points at all concentration levels.

The values shown for  $c_{p0}^{max}$  are greater than the corresponding value of  $c_{p0}(h_{ob}^{max})$  as expected, since  $c_{p0}^{max}$  is a less restrictive pairing of maximum values. The upper end of the range of values for  $c_{p0}^{max}$  is about 30 ppb greater than that for  $c_{p0}(h_{ob}^{max})$ , attesting to a phase lag between the time of the  $O_3$  maxima predicted by ROM1 and the maxima observed at the monitoring stations. The results for ROM1 layer 1 are not significantly different than those shown here for layer 0.

The corresponding plots of bias versus observed maximum concentration are shown in Figure 18. The measure of bias,  $d_{B0}^{max} = c_{ob}^{max} - c_{p0}^{max}$ , is plotted in 18a and  $d_{A0}^{max} = c_{ob}^{max} - c_{p0}(h_{ob}^{max})$  is plotted in 18b. The trends displayed in these scatterplots show a fairly strong correlation between the bias and the observed maximum concentration with increased levels of underprediction at higher ambient  $O_3$  concentrations. Much of this trend

## LAYER ZERO MAX VS RECEPTOR MAX

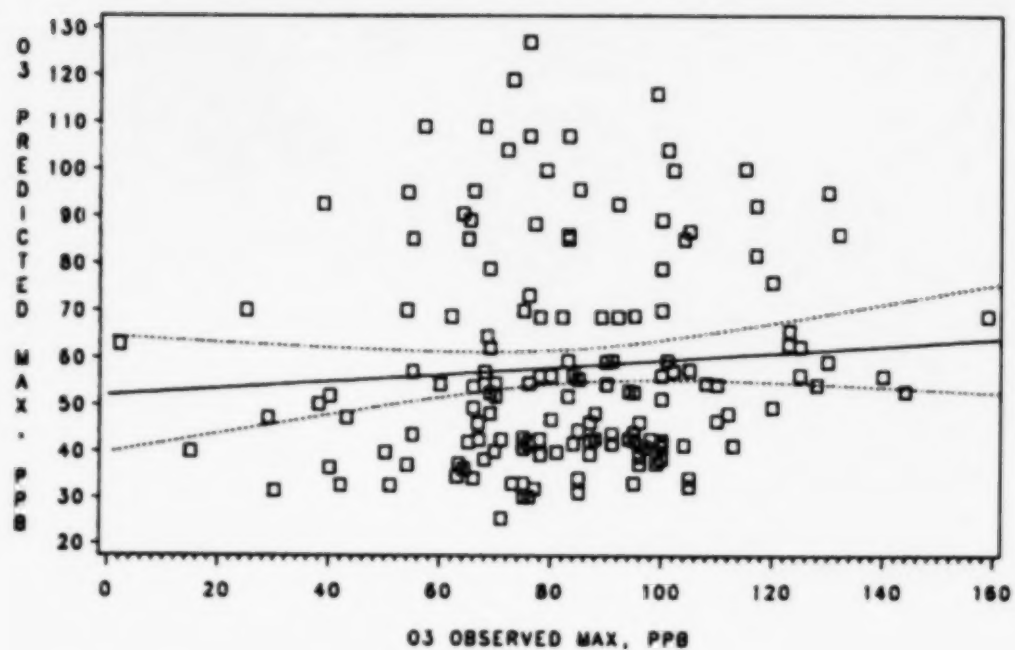


Figure 17a. Scatterplot of  $c_{p0}^{\max}$  vs.  $c_{ob}^{\max}$  for  $O_3$  concentrations at all surface monitoring sites on 3-4 August 1979.

## LAYER ZERO VALUE AT TIME OF OBSERVED MAX

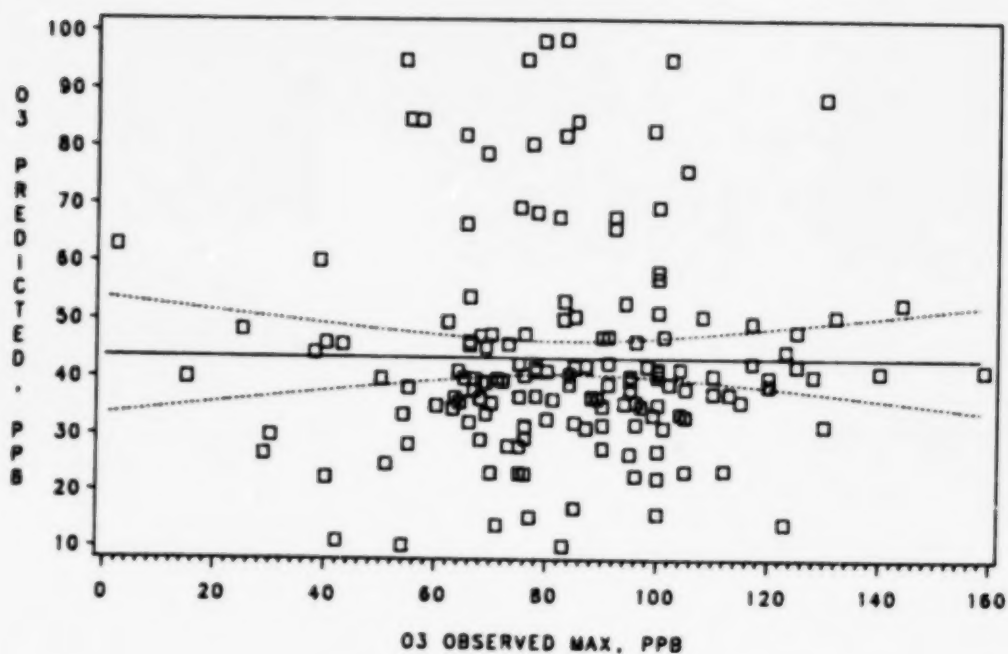


Figure 17b. Scatterplot of  $c_{p0}(h_{ob}^{max})$  vs.  $c_{ob}^{max}$  for  $O_3$  concentrations at all surface monitoring sites on 3-4 August 1979.

## LAYER ZERO BIAS VS RECEPTOR MAX

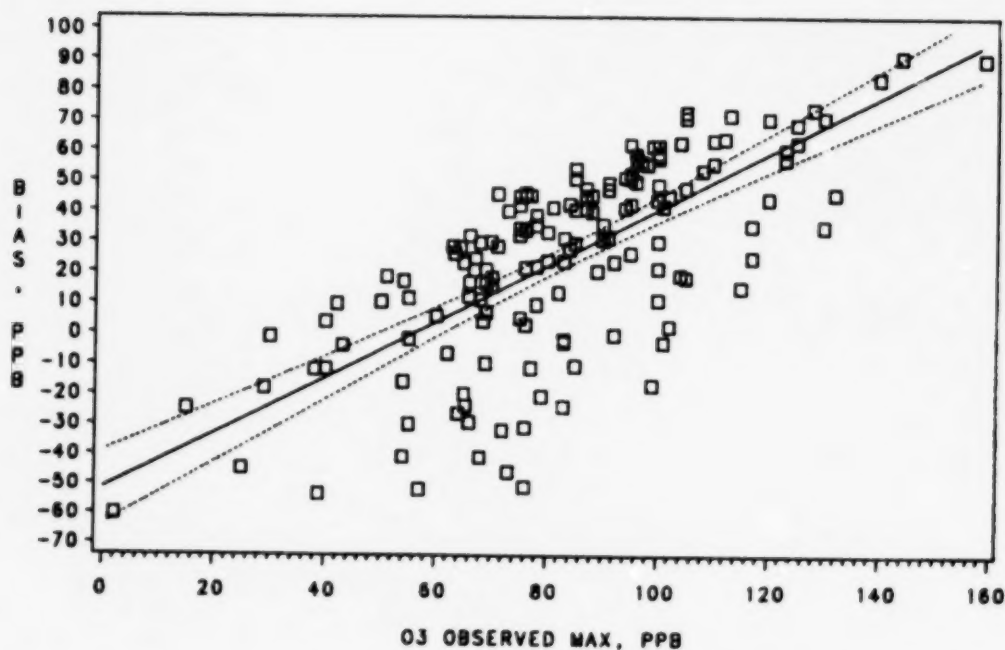


Figure 18a. Scatterplot of  $d_{BO}^{max}$  vs.  $c_{ob}^{max}$  for  $O_3$  concentrations at all surface monitoring sites on 3-4 August 1979.

## LAYER ZERO BIAS AT TIME OF RECEPTOR MAX

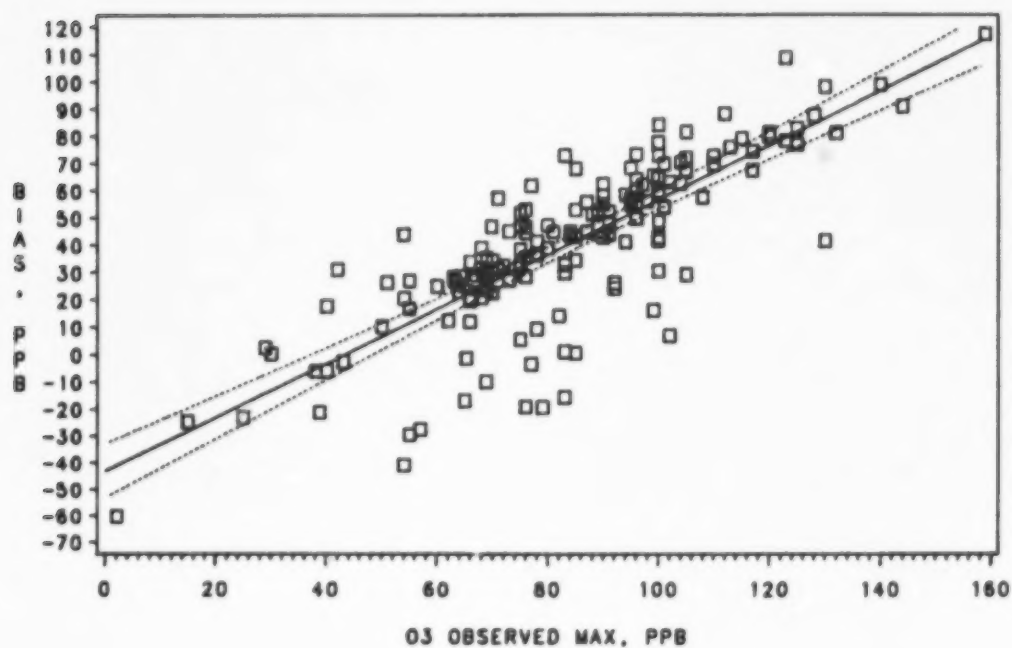


Figure 18b. Scatterplot of  $d_{A0}^{\max}$  vs.  $c_{ob}^{\max}$  for  $O_3$  concentrations at all surface monitoring sites on 3-4 August 1979.

is understood to be caused by the narrow range of background concentrations predicted at many of the monitoring site locations that showed a wide range of observed maxima. Again, the problem relates to the initial and boundary  $O_3$  tropospheric background concentration imposed on the model and the subsequent pervasiveness of this value in the predicted model results. The bias values are correspondingly larger for  $d_{AO}^{max}$  than for  $d_{BO}^{max}$  because of the more restrictive pairing implied in  $d_{AO}^{max}$ .

A summary of statistics from the local maximum values analysis for the model simulation is presented in Table 5. Results from the full data set as well as the data subset of  $O_3$  concentrations where  $c_{ob}$ ,  $c_{p0}$ , and  $c_{p1}$  are all greater than 50 ppb are given. The number of receptor stations dropped from 156 in the full data set to 47 in the data subset. Interestingly, the average observed maximum value increased by only 2-4 ppb from the data set to the subset because there were very few observed maxima less than 50 ppb at the monitoring site locations. Conversely, the average model predictions increased by 20-30 ppb from the data set to the subset because of the large number of values near the background  $O_3$  level. For the looser pairing of observed and predicted maximum values the average bias at all receptor sites was 24.8 ppb on 3 August, representing a 34% underprediction and 25.3 ppb on 4 August, representing a 33% underprediction, for model layer 0. For layer 1 the corresponding values are 23.2 ppb (32% underprediction) on 3 August, and 23.3 ppb (30% underprediction) on 4 August. In the data subset where the lower  $O_3$  values are excluded the results show a marked improvement. On 3 August, the average bias for layer 0 was 11.3 ppb (15% underprediction) and on 4 August, it was 5.6 ppb (7% underprediction). For layer 1 the corresponding values are 9.2 ppb (12% underprediction) on 3 August, and 2.7 ppb (3% underprediction) on 4 August. A listing of all surface monitoring sites and their respective observed and predicted maximum values on both days is given in Appendix B.

The purpose of the global maximum values analysis is to attempt to isolate individual areas or plumes of high  $O_3$  concentrations in the model predictions and the ambient observations for comparison. The perspective

TABLE 5. SUMMARY OF ROM1 RESULTS FOR LOCAL MAXIMUM  
VALUES FOR 3-4 AUGUST 1979

|                                        | Full Data Set |       | Data Subset<br>( $c_{ob}, c_{p0}, c_{p1} > 50$ ppb) |       |
|----------------------------------------|---------------|-------|-----------------------------------------------------|-------|
|                                        | 79215         | 79216 | 79215                                               | 79216 |
| n                                      | 156           | 154   | 47                                                  | 48    |
| $R_{c_{ob}}^{max}$ (ppb)               | 73.2          | 77.8  | 75.5                                                | 81.8  |
| $R_{c_{p0}}^{max}$ (ppb)               | 48.4          | 52.5  | 64.2                                                | 76.2  |
| $R_{c_{p0}}^{max}(h_{ob}^{max})$ (ppb) | 40.0          | 43.5  | 60.0                                                | 68.9  |
| $R_{c_{p1}}^{max}$ (ppb)               | 50.0          | 54.5  | 66.3                                                | 79.1  |
| $R_{c_{p1}}^{max}(h_{ob}^{max})$ (ppb) | 41.6          | 45.1  | 62.0                                                | 71.4  |
| $R_{d_{B0}}^{max}$ (ppb)               | 24.8          | 25.3  | 11.3                                                | 5.6   |
| $R_{d_{A0}}^{max}$ (ppb)               | 33.2          | 34.3  | 15.5                                                | 12.9  |
| $R_{d_{B1}}^{max}$ (ppb)               | 23.2          | 23.3  | 9.2                                                 | 2.7   |
| $R_{d_{A1}}^{max}$ (ppb)               | 31.6          | 32.7  | 13.5                                                | 10.4  |
| $R_{s_{d_{B0}}}^{max}$ (ppb)           | 26.9          | 33.6  | 21.9                                                | 32.6  |
| $R_{s_{d_{A0}}}^{max}$ (ppb)           | 26.8          | 32.1  | 21.4                                                | 30.9  |
| $R_{s_{d_{B1}}}^{max}$ (ppb)           | 26.9          | 33.8  | 21.9                                                | 32.3  |
| $R_{s_{d_{A1}}}^{max}$ (ppb)           | 27.0          | 32.3  | 21.5                                                | 30.7  |

in this analysis is broader than that in the local maximum values analysis in that model predictions at the same location as the observation are not necessarily required. Instead, the eligible area from which the model prediction is chosen is defined to be the coherent region of concentrations, or plume, from which the observation comes. This less restrictive pairing permits us to match observations and predictions based on supposedly similar phenomenological events in the physical processes producing the maximum  $O_3$  values. This perspective also permits us to include a larger area than the single site location where the maximum value occurred.

A number of problems arise in the implementation of this analysis. The number and spatial distribution of surface monitoring sites for  $O_3$  is not ideal for defining plumes over the NEROS region (see Figures 1,4, and 5). The sites are primarily located in and very close to urban areas, limiting the ability to define the downwind extent of an urban plume. We shall rely on the interpolated wind field used by RUM1 to help define the projected plume location from major source areas in the NEROS region. We desire to include areas that show consistent plume transport as well as numerous monitoring sites near the projected plume path.

Figure 19 shows the 12-hour projected forward trajectories starting at 0600 h on 3 August from some of the major urban source areas in the NEROS region. The stars indicate the starting location and the dots are the monitoring site locations. The trajectories are based on the RUM1 layer 1 wind field. The analogous plot for 4 August is shown in Figure 20. On the first day the trajectories from cities in the western part of the grid show fairly consistent directions while in the east the influence of the offshore stationary front on the wind flows is evident by the varying directions, especially in the New York and Philadelphia trajectories which show recirculation patterns. On 4 August the eastern trajectories all appear from the NNW, except for Boston which shows a slower flow from the SE. The western trajectories are from the west and SW.

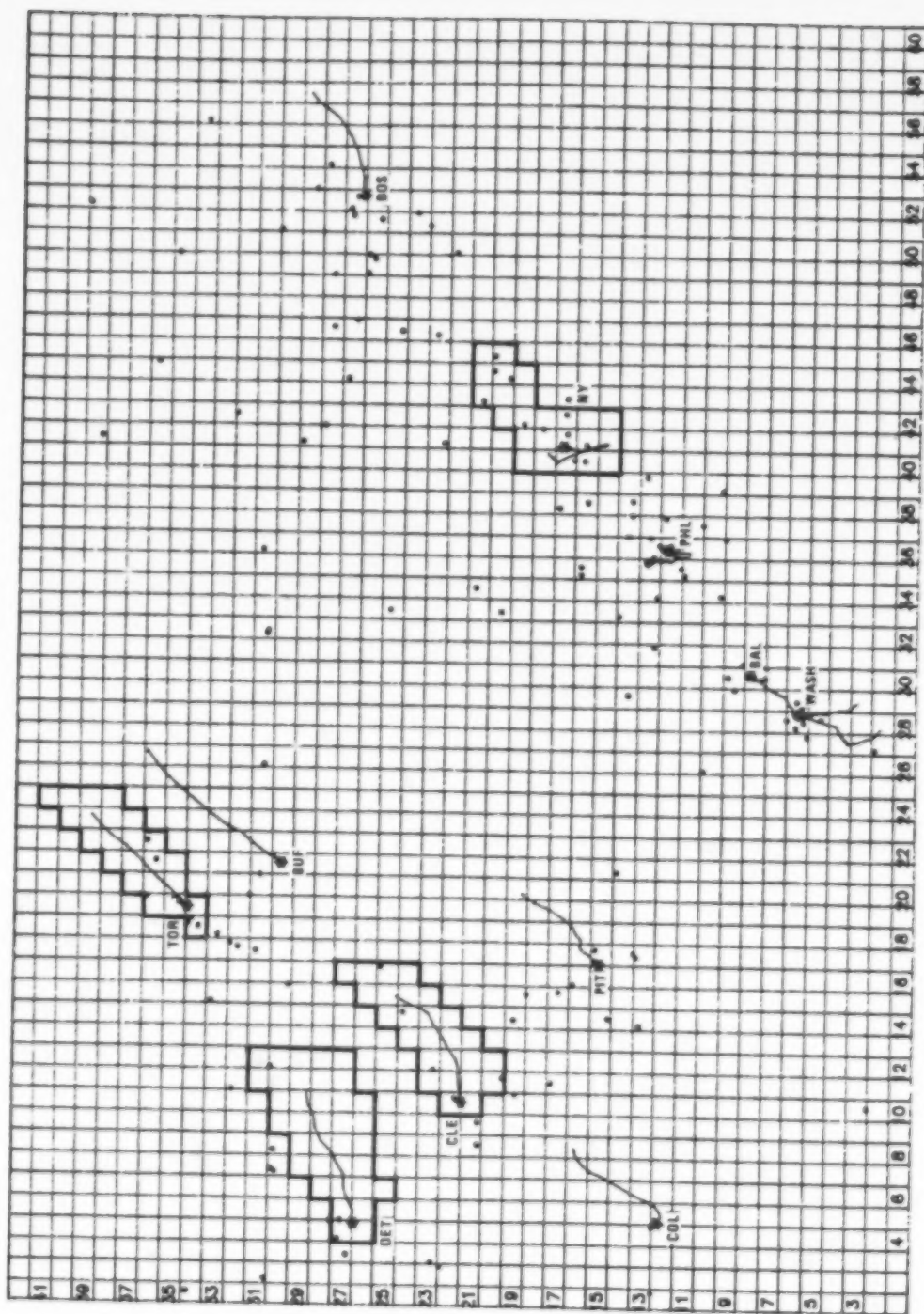


Figure 19. ROM1 grid showing projected 12-hr forward trajectories on 3 Aug. 1979 from selected urban source areas.

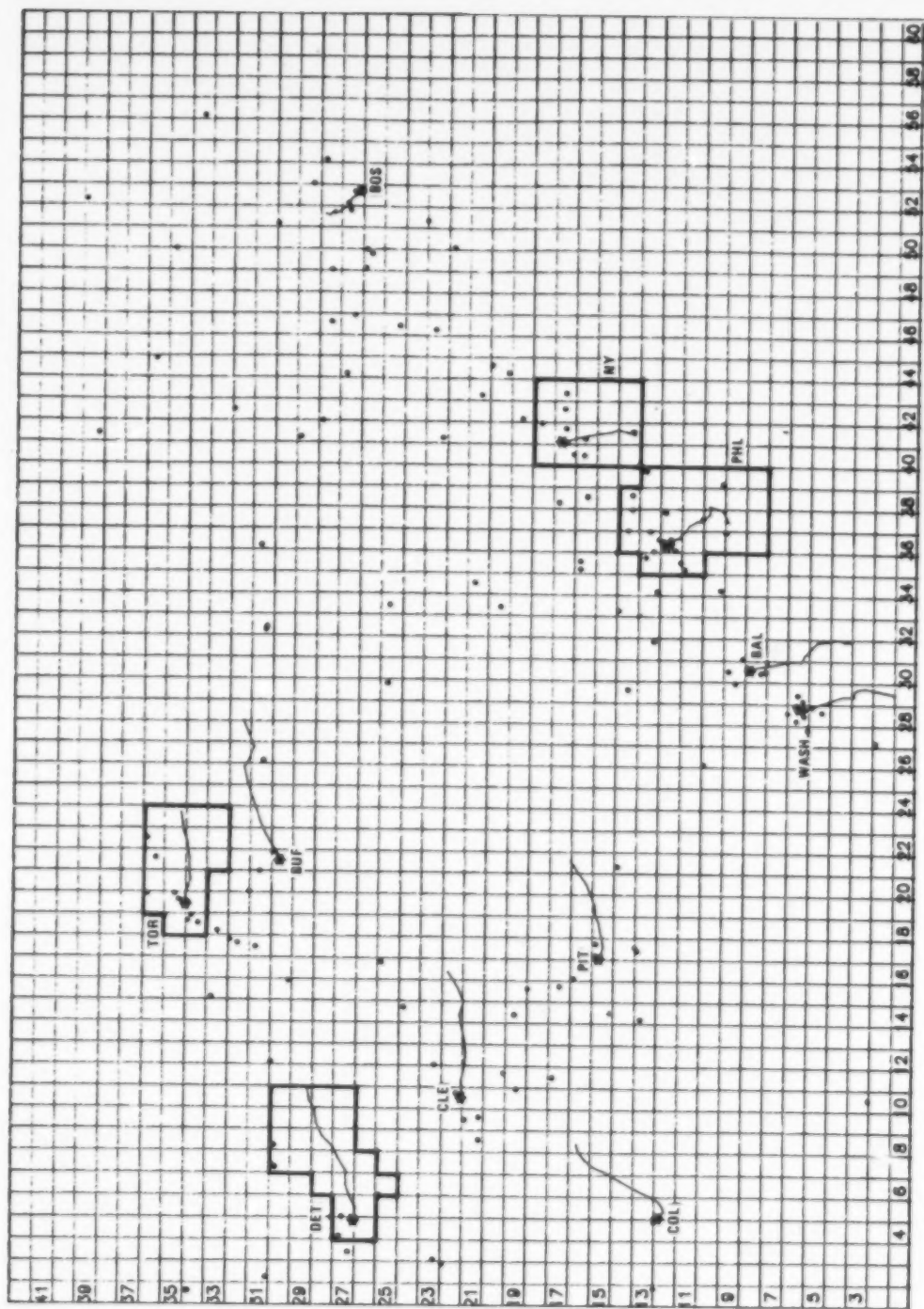


Figure 20. ROM1 grid showing projected 12-hr forward trajectories on 4 Aug. 1979 from selected urban source areas.

It is immediately apparent that few of the trajectories have sufficient monitoring sites in their vicinity to substantiate an  $O_3$  plume. Therefore, in choosing which projected plumes to study further and determining their spatial extent we examine the contoured field of  $O_3$  concentrations from ROM1 layer 1 on both days at 1400 h and 1600 h in Figures 21 and 22, as well as the maximum observed values of  $O_3$  shown in Figures 4 and 5. In specific instances the aircraft sampling measurements are useful in locating  $O_3$  plumes also. On 3 August significant  $O_3$  plumes are projected downwind of Detroit and Toronto and near the New York area. Observed concentrations are also high along the south shore of Lake Erie so the Cleveland area will be included in the analysis also. Some relatively high  $O_3$  values are observed also in the Washington and Philadelphia areas, although the ROM1 predictions show only minor perturbations in these areas. The variable cloud cover and occasional rain showers may have allowed just enough solar radiation through to promote some local  $O_3$  generation there, but the hour-averaged and spatially interpolated data used by the model apparently did not allow for the same effect. The ROM1 grid areas shown in Figure 19 with the darkened borders are the plume areas chosen for further analysis on 3 August.

On 4 August significant  $O_3$  plumes are again projected downwind of Detroit and Toronto. Since the greater portion of these plumes are over the Great Lakes, comparison with monitoring data are not easily made. However, stations near the periphery of the lakes do show higher values of  $O_3$  (Figure 5) so these plumes will be considered for analysis. Higher  $O_3$  areas also exist along coastal and southern New Jersey in both model predictions and observations. These areas coincide with the projected downwind extent of the New York and Philadelphia plumes, and they are included in the global maximum values analysis. Relatively high  $O_3$  values (as high as 140 ppb) are observed in the immediate Washington, D.C. area on 4 August, although the model's predictions in this area are not much above background. The discrepancy here is unresolved and may need more simulations to determine the adequacy of the emission data and other inputs in this part of the grid. The areas with darkened borders in Figure 20 are the plume areas chosen for further analysis on 4 August.



Figure 21a. Contours of hour-averaged predicted  $O_3$  concentrations in ROM1 layer 1 on 3 Aug. 1979 at 1400 h, LST.



Figure 21b. Contours of hour-averaged predicted  $O_3$  concentrations in ROM1 layer 1 on 3 Aug. 1979 at 1600 h, LST.



Figure 22a. Contours of hour-averaged predicted  $O_3$  concentrations in ROM1 layer 1 on 4 Aug. 1979 at 1400 h, LST.



Figure 22b. Contours of hour-averaged predicted  $O_3$  concentrations in ROM1 layer 1 on 4 Aug. 1979 at 1600 h, LST.

A more detailed depiction of the Toronto plume on 3 August is given in Figure 23. The projected  $O_3$  plume is evident in the contoured model predictions of daily maximum  $O_3$  downwind of the center location of Toronto, indicated by the "+". The surface monitoring sites and the maximum concentration observed at each are also shown. Two of the downwind sites observing maximum  $O_3$  between 80 and 100 ppb show excellent agreement with model predictions at those locations. Another site located in the area of the projected plume appears to have an anomalously low maximum value of  $O_3$  of 55 ppb. This site may have been directly affected by a nearby source of  $NO_x$  emissions during the day. There were no surface monitoring stations in the vicinity of the projected plume maximum of 144 ppb. Note that the maximum values observed at the stations nearest to the central urban area show considerable variation at close range to each other. This is not unexpected given the heterogeneous emissions patterns of a large urban area. The expected variance in concentrations within a grid cell is estimated within the formulation for model layer 0 and will be evaluated with field data using the second generation regional model, ROM2.

In estimating model performance in the global maximum perspective we define three different comparisons of model predicted concentration with the maximum observed concentration,  $c_{ob}^{max}$ , in the  $O_3$  plume. First, there is the predicted maximum at the same location as the monitoring site of the observed maximum. Second, there is the maximum predicted concentration at any of the monitoring site locations in or near the projected plume, and finally there is the maximum concentration found in the grid cell at the center of the projected  $O_3$  plume. These three values are designated (for ROM1 layer 1) as  $c_{pl-A}^{max}$ ,  $c_{pl-B}^{max}$ , and  $c_{pl-C}^{max}$ , respectively and proceed from the most to the least strict pairing of concentrations in the global maxima analysis. For the Toronto plume on 3 August,  $c_{pl-A}^{max} = c_{pl-B}^{max} = 110$  ppb at site ORO since the model-predicted maximum  $O_3$  occurred at the same site as the observed maximum, and  $c_{pl-C}^{max} = 144$  ppb at cell location (23,38). There are also corresponding values for ROM1 layer 0 that are not discussed here but will be tabulated later. The measures of bias resulting from these pairings are  $d_{pl-A}^{max}$ ,  $d_{pl-B}^{max}$ ,

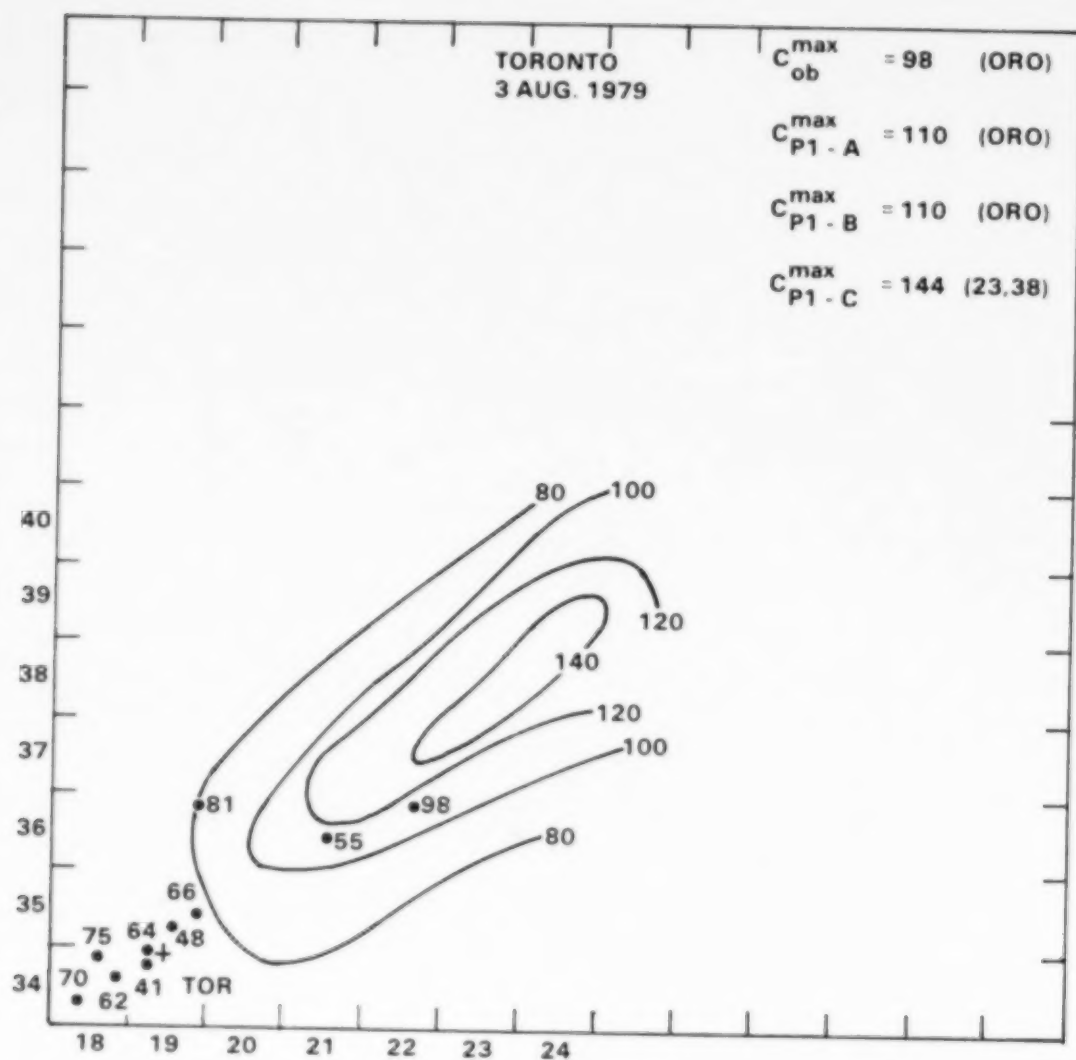


Figure 23. Predicted (ROM1 layer 1) and observed maximum  $O_3$  concentrations (ppb) downwind of Toronto on 3 Aug. 1979.

and  $d_{p1-C}^{\max}$  and have values of -12, -12, and -46 ppb, respectively, for this plume.

Figure 24 presents the time series of  $O_3$  concentrations for station ORO on 3 August. It is evident that the predicted concentrations do not fall to the low levels that the monitoring stations observe for the dark hours. The predicted values shown here are for model layer 1, although layer 0 values are not very different. Also, the peak value is predicted earlier in the day than that observed at the station. A difference in time between the predicted and observed peak  $O_3$  values is not uncommon in photochemical dispersion models and is often the result of the chemical kinetics in the model being more or less reactive than the existing atmospheric case. Transport and dispersion of the precursor emissions also, of course, can affect the timing of the peak at a given location. In this case the model predicts the maximum  $O_3$  concentration within the plume to occur later in the day at 1700 h downwind of ORO. That is closer to the time of the observed maximum at ORO.

The case of the Detroit and Cleveland areas are considered together in Figure 25. The ROM1 does not develop an  $O_3$  plume downwind of Cleveland on 3 August as can be seen by the nearly flat gradient in concentrations. Surface observations to the northeast however indicate two stations downwind, near the Lake Erie shoreline, showing maxima of 159 and 95 ppb. As discussed in Section 2, these higher concentrations are not the result of photochemical generation from Cleveland, but rather reflect the previous day's  $O_3$  in an aged plume from Detroit or elsewhere that had been advected over Lake Erie and fumigated to the surface during the morning hours. Both the time-series records of surface concentrations at these stations and aircraft observations of  $O_3$  aloft made by the WSU aircraft (flight 8 - see Figure 6) later in the day on 3 August over the eastern end of Lake Erie and south of Buffalo help substantiate this. Also, the maximum concentration in the model-predicted plume downwind of Detroit was 158 ppb on 3 August, very close to the value observed at the CNE station on the south shore of Lake Erie. Presumably if the maximum  $O_3$  generated in the Detroit plume from the previous day was of a

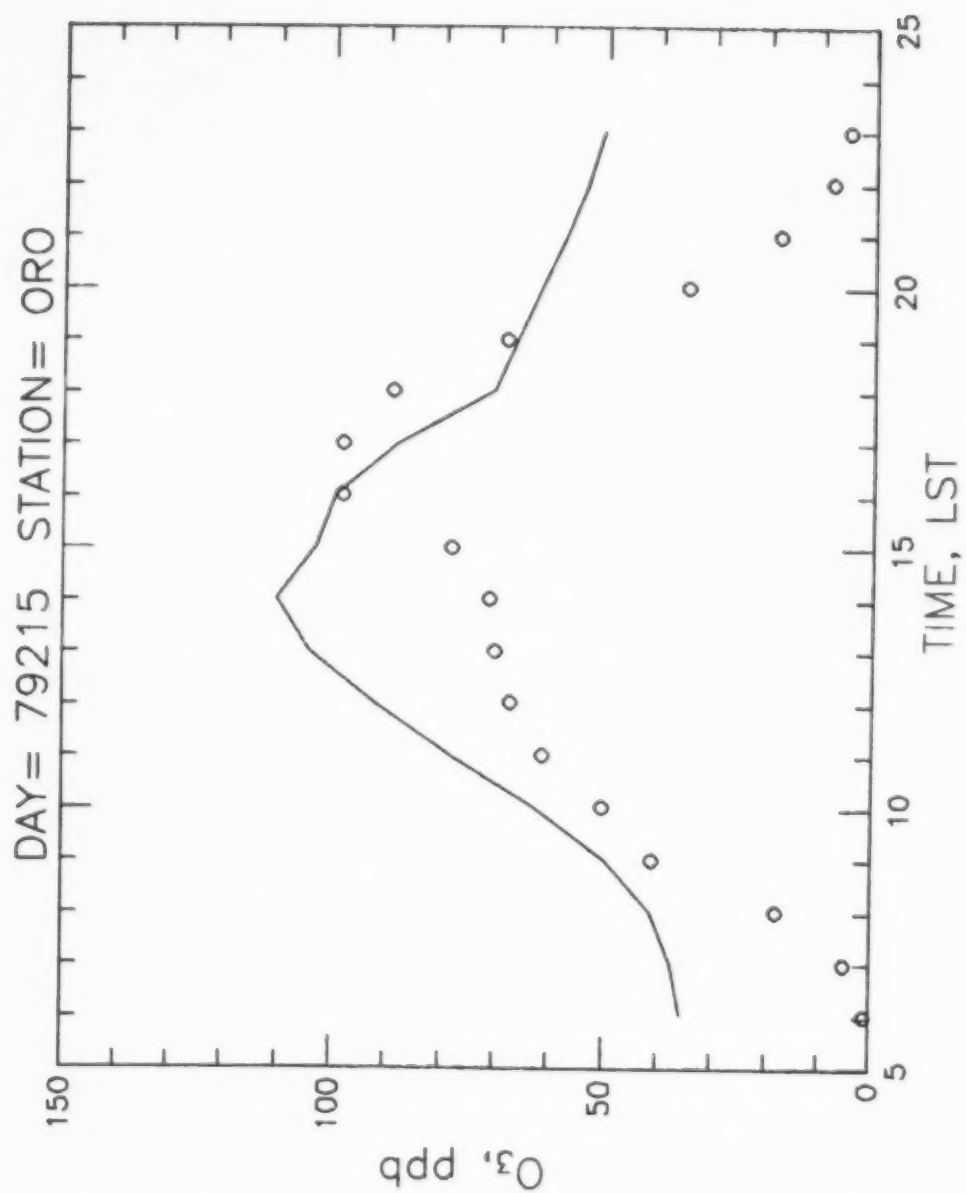


Figure 24. Time-series of predicted (ROM1 layer 1) and observed O<sub>3</sub> concentrations at monitoring site ORO on 3 Aug. 1979.

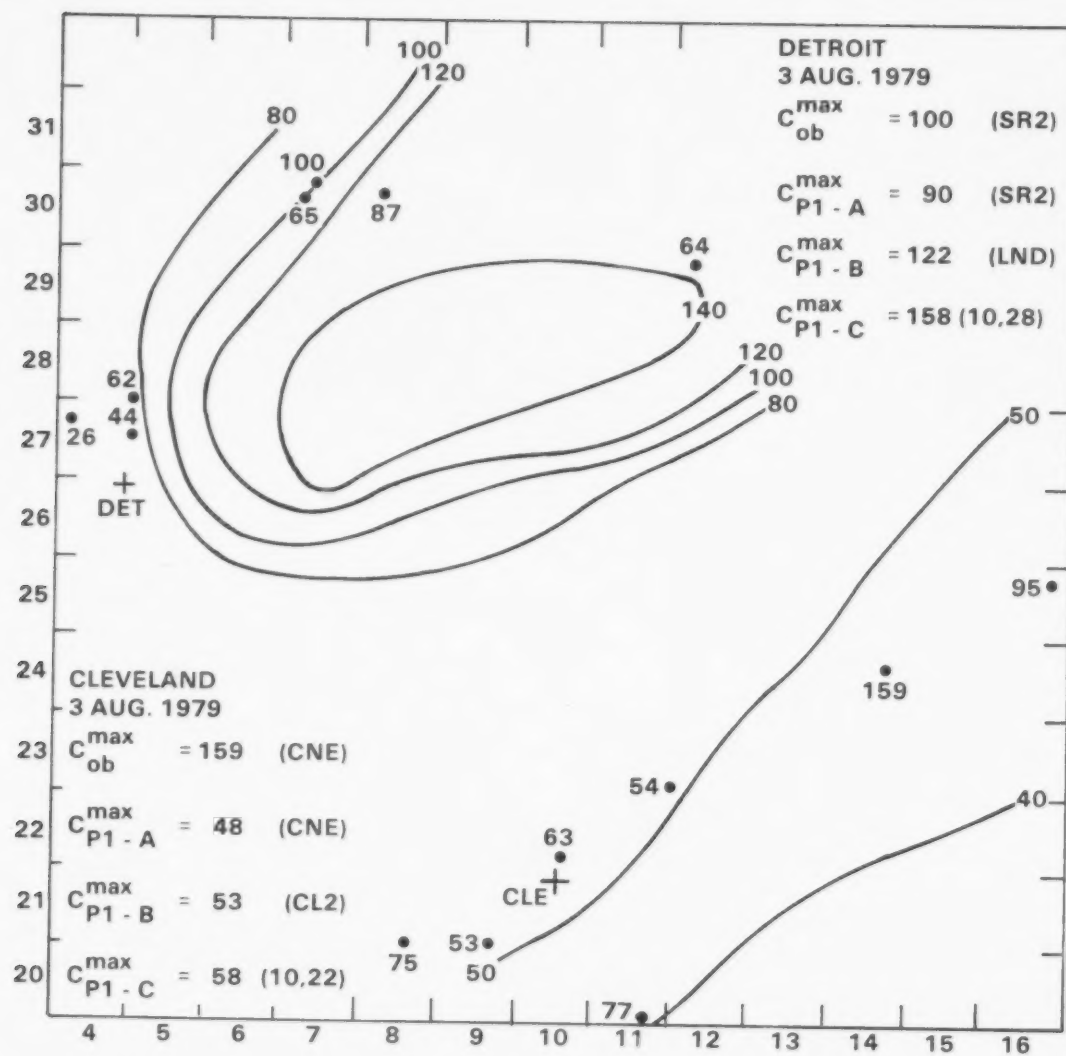


Figure 25. Predicted (ROM1 layer 1) and observed maximum  $O_3$  concentrations (ppb) downwind of Detroit and Cleveland on 3 Aug. 1979.

similar magnitude, the more westerly winds on 2 August would have carried the plume over Lake Erie and to the vicinity of these south shore stations. The test simulation discussed here was initialized with clean tropospheric concentrations of all species and thus does not address the issue of carry-over of concentrations from 2 August. The Cleveland area is therefore dropped from further consideration because the model predictions and the surface monitors do not support plume generation here.

The ROM1 O<sub>3</sub> predictions clearly show a plume emanating from the Detroit-Windsor area northeast into Ontario on 3 August. The maximum predicted concentration within this plume,  $c_{pl-C}^{max}$ , is 158 ppb at grid cell (10,28) at 1700 h, LST. The one surface station closest to the area of maximum predicted concentrations shows a measured maximum of only 64 ppb, while the model-predicted O<sub>3</sub> value for the site is nearly twice as much. Stations along the northern edge of the plume show somewhat closer agreement. For instance, the maximum value observed in the projected plume area,  $c_{ob}^{max}$ , was at Sarnia, Ontario (SR2) at 100 ppb and the maximum predicted value at that site was 90 ppb, a 10% underprediction. The time-series of observed and predicted O<sub>3</sub> concentrations for SR2 is shown in Figure 26. The observed peak is attained rather early in the day, at 1200 h, indicating the likelihood of even higher concentrations farther downwind. The model predictions again stabilize at higher levels during the nighttime hours than do the observations.

The final plume analyzed for this day is that for New York. The projected 12-hour forward trajectory for New York shown in Figure 19 indicates some looping and recirculation in the air parcels in the vicinity of the stationary front lying very close to New York. This introduces a larger degree of uncertainty in establishing an accurate trajectory path, but we do attempt to locate an O<sub>3</sub> plume here because observed concentrations were relatively high at several surface monitoring stations to the northeast of New York. Figure 27 shows the contoured predictions of maximum O<sub>3</sub> concentrations along the projected trajectory path from New York which has been expanded and lengthened somewhat for this analysis to allow for

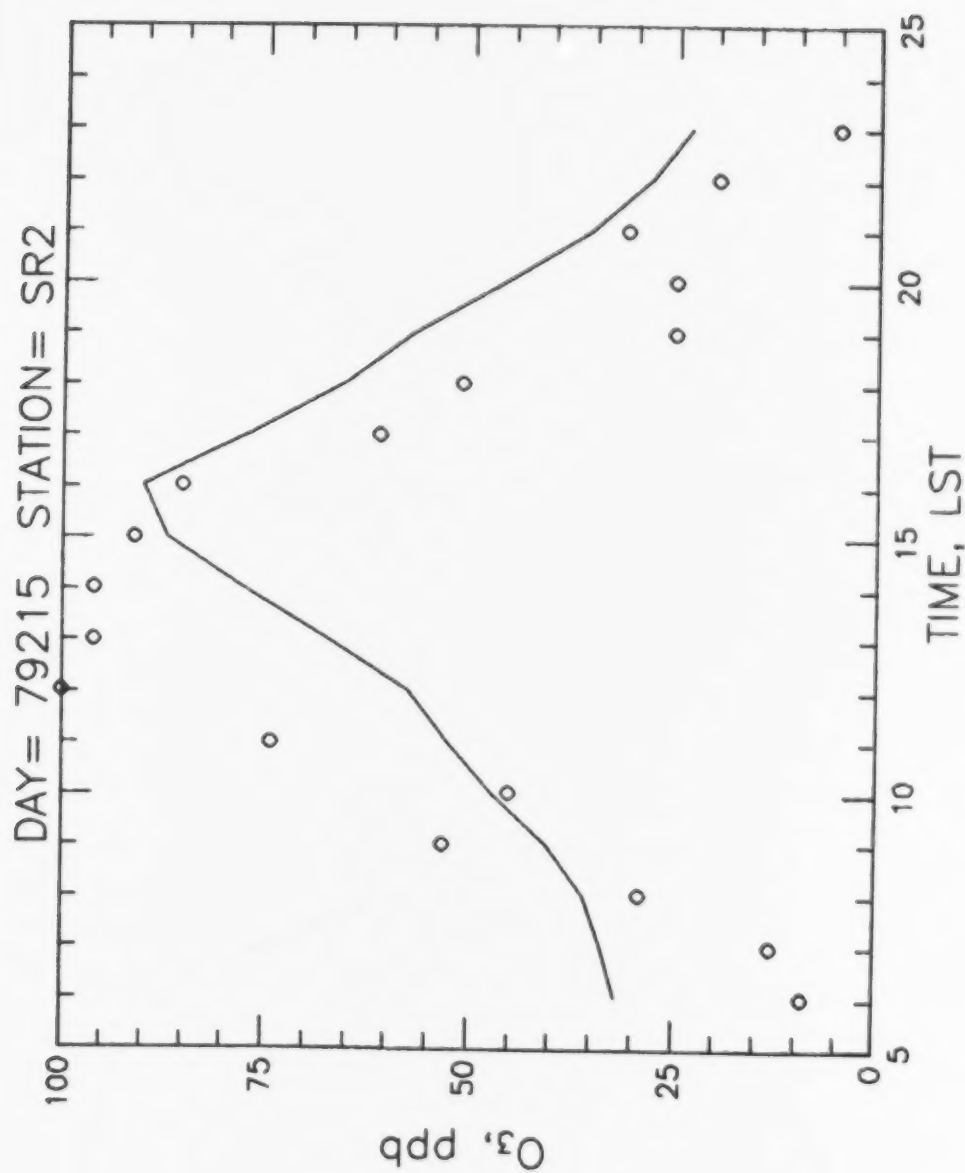


Figure 26. Time-series of predicted (ROM1 layer 1) and observed  $O_3$  concentrations at monitoring site SR2 on 3 Aug. 1979.

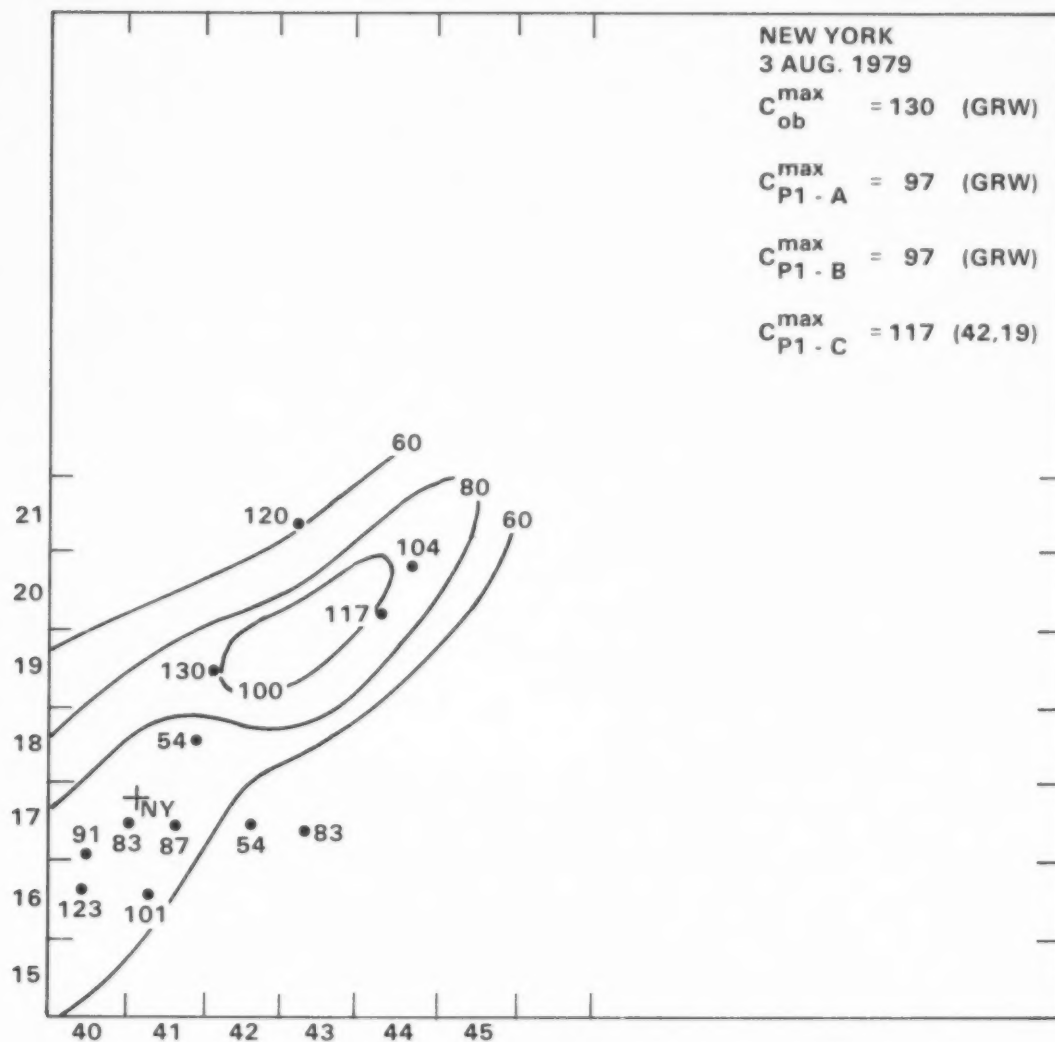


Figure 27. Predicted (ROM1 layer 1) and observed maximum  $O_3$  concentrations (ppb) downwind of New York on 3 Aug. 1979.

the greater uncertainty in the looping path. An  $O_3$  plume is observed in the predictions to the northeast of New York with the maximum,  $c_{pl-C}^{max}$ , of 117 ppb at grid cell (42,19). Fortuitously there are several monitoring sites in the vicinity of the predicted plume, and it appears that its predicted location is quite good. The maximum observed concentration,  $c_{ob}^{max}$ , occurred at GRW in Connecticut, located in the same grid cell as  $c_{pl-C}^{max}$ . The magnitude of the observed maximum was 130 ppb, implying a 10% underprediction when  $c_{ob}^{max}$  is paired with  $c_{pl-C}^{max}$ . The model prediction at GRW,  $c_{pl-A}^{max}$  (and  $c_{pl-B}^{max}$ ), is 97 ppb, giving a 25% underprediction with the more strict pairing. A station at the northern edge of the projected  $O_3$  plume shows a maximum concentration of 120 ppb while the prediction is around 60 ppb. Apparently, while the center portion of the plume has been well-located the breadth of the high concentration area has been underestimated. Figure 28 presents the concentration time-series at station GRW on 3 August 1979. The timing of the peak concentration coincides within one hour between observed and predicted  $O_3$  maxima in accordance with the well-located predicted plume position. The temporal concentration gradients are smaller in the ROM1 predictions at this location than the observations and, in fact, the predicted  $O_3$  concentration appears to level off into the evening hours while the surface monitor indicates a rapid depletion of  $O_3$  toward evening.

Another interesting aspect of the concentration field near New York occurs to the south and southwest of the city where relatively high  $O_3$  values (up to 123 ppb) are observed at monitoring stations there. The initial path of the trajectory from New York is in a southerly direction before looping to the northeast so it is not entirely surprising to find higher concentrations there. The model predictions, however, do not exhibit this secondary peak to the southwest, possibly because the model has advected the precursor emissions farther along the trajectory before photochemical generation could get well underway.

Over the evening and nighttime periods from 3 August into 4 August, the ROM1 advects the predicted  $O_3$  plume from Detroit east and northeast over Lake Erie and eventually to the south of Toronto over Lake Ontario. The more stable

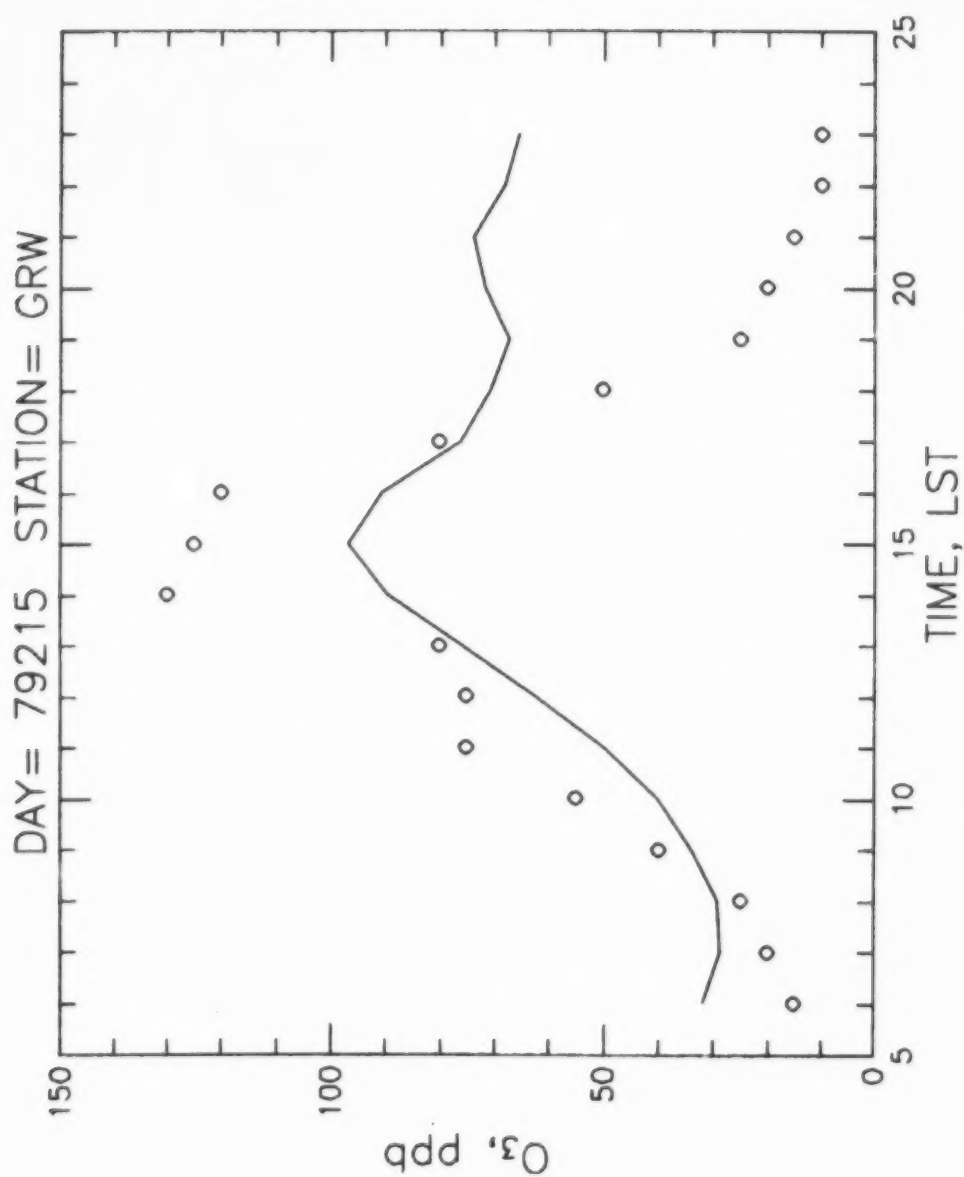


Figure 28. Time-series of predicted (ROM1 layer 1) and observed  $O_3$  concentrations at monitoring site GRW on 3 Aug. 1979.

atmosphere over the lake waters is modeled by ROM1 and manifests in allowing the concentrations within the now-aging Detroit plume to remain rather high. The Toronto forward trajectory for 4 August shows a movement to the east of the urban area. Contours of the maximum predicted hourly  $O_3$  for model layer 1 downwind of Toronto are shown in Figure 29. The highest predicted values, in excess of 220 ppb, are east of Toronto over Lake Ontario. The Toronto plume on 4 August is shown by the simulation to have been transported into the area of the day-old Detroit plume over the lake. The synergism between the new and older plumes has produced rather high predicted levels. None of the surface monitoring stations is located in a position to validate the highest  $O_3$  levels. Site OR0, northeast of Toronto, had an observed maximum  $O_3$  value of 101 ppb on 4 August. The ROM1 predictions show this site location to be just on the periphery of the  $O_3$  plume, and the time-series of concentrations here, shown in Figure 30, clearly shows not only an underprediction, but also little correspondence in the temporal pattern. The observations appear to show that OR0 was more directly affected by the Toronto plume than the predictions indicate. The maximum predicted concentration at OR0 was 66 ppb.

Examining the monitoring sites upwind of Toronto might indicate the existence of the transported Detroit plume on 4 August. The results here are mixed. Two sites near the lakes, St. Catharines in Ontario and Niagara Falls in New York, indicate maximum  $O_3$  values less than 60 ppb. The other sites show a range of 76-92 ppb, certainly more than background but not at the 100 and over ppb level of the predictions. It appears that the effect of the older transported plume has been overemphasized by the model. The highest  $O_3$  prediction occurring at monitoring site locations,  $c_{pl-B}^{max}$ , was 107 ppb at STC and NG2, the same two sites that showed the lower maximum observed values.

WSU conducted several aircraft transects on 3-4 August that approached the area of interest of the Toronto-(old) Detroit predicted plume. The shaded grid cells in Figure 29 are those where the WSU aircraft  $O_3$  monitor observed values between 100 and 120 ppb at about 1000 m above ground between the hours of 2000 on 3 August, and 0000 on 4 August. It thus appears that an older plume was advected into this area aloft, although judging from the sampling

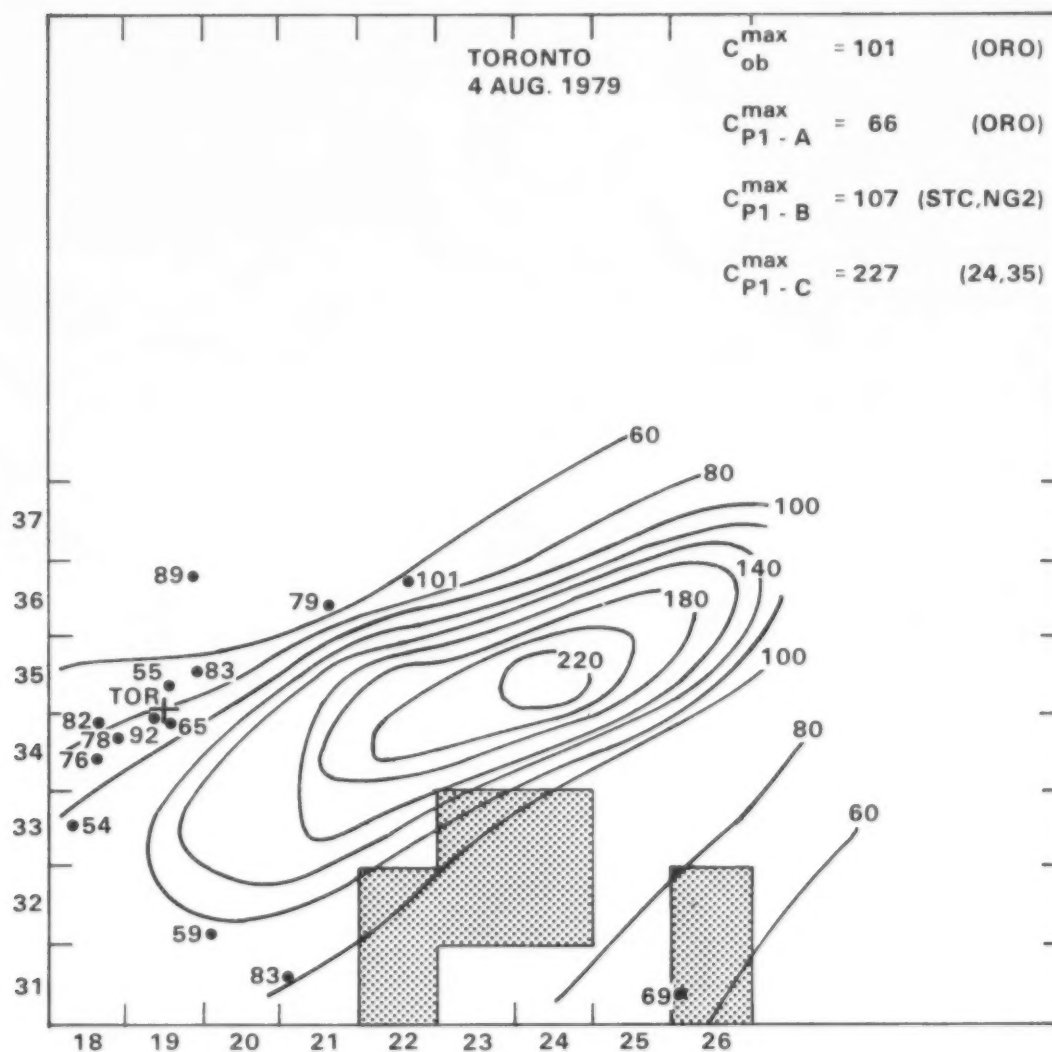


Figure 29. Predicted (ROM1 layer 1) and observed maximum  $O_3$  concentrations (ppb) downwind of Toronto on 4 Aug. 1979.

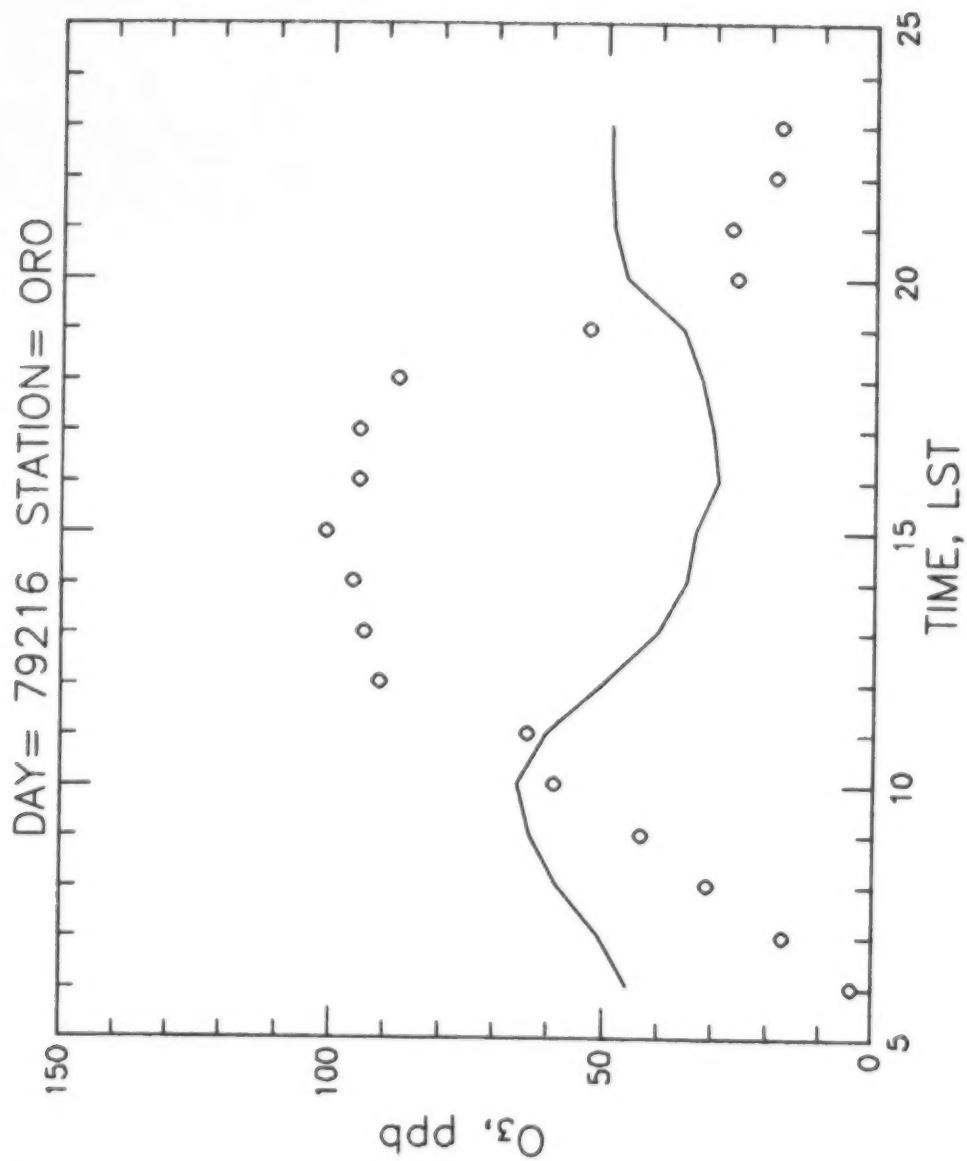


Figure 30. Time-series of predicted (ROM1 layer 1) and observed  $O_3$  concentrations at monitoring site ORO on 4 Aug. 1979.

time and location this may have been the remnants of a plume from the Detroit area on 2 August. The surface monitoring site at Monroe, New York, near Rochester, showed maximum hourly  $O_3$  concentrations of 61 ppb on 3 August and 69 ppb on 4 August, while the WSU aircraft sampled  $O_3$  as high as 127 ppb aloft in the same vicinity during the night hours spanning 3-4 August. It appears that the effects of the plume aloft were not entirely felt at the surface at this particular site. If the higher observed concentrations aloft are, in fact, from the Detroit plume of 3 August, the ROM1 has predicted its location somewhat to the north of its true position.

The forward trajectory from Detroit on 4 August travels to the east of the city and later takes a northeast turn. The axis of the maximum predicted  $O_3$  concentration area from Detroit, as seen in Figure 31, is oriented southeast from the city over Ontario and western Lake Erie. The maximum concentration,  $c_{pl-C}^{max}$ , in the plume is 162 ppb at grid cell (8,26). The surface monitoring stations showing the largest hourly level of  $O_3$  are SR2 and PTR, northeast of Detroit, where 99 ppb was observed. There appears to be a bifurcation in the predicted plume with a secondary maximum just west of station PTR. The maximum  $O_3$  concentration predicted at the PTR site,  $c_{pl-B}^{max}$ , is 88 ppb, an 11% underprediction. The time-series of observed and predicted  $O_3$  concentrations at PTR is shown in Figure 32. The hourly observed values show a bimodal peak with the greater value occurring at 1800 h, LST. The predicted pattern of values is smoother with the peak occurring at 1600 h, LST. There are only 2 monitoring stations south of Detroit, near the periphery of the predicted plume. At WNS and DT4 the predicted  $O_3$  peak values were both 94 ppb, while the observed peaks were 39 and 74 ppb, respectively. The wide variation in values at these near-by stations attests to their central urban locations. No surface monitoring sites lie close to the central area of the predicted plume.

The RTI aircraft, however, flew a sampling transect in a north-south line during the afternoon of 4 August, and measured elevated  $O_3$  concentrations in the exact vicinity of the predicted Detroit plume. The specific flight is labeled F in Figure 7, and corresponds to a north-south run along column 8 of

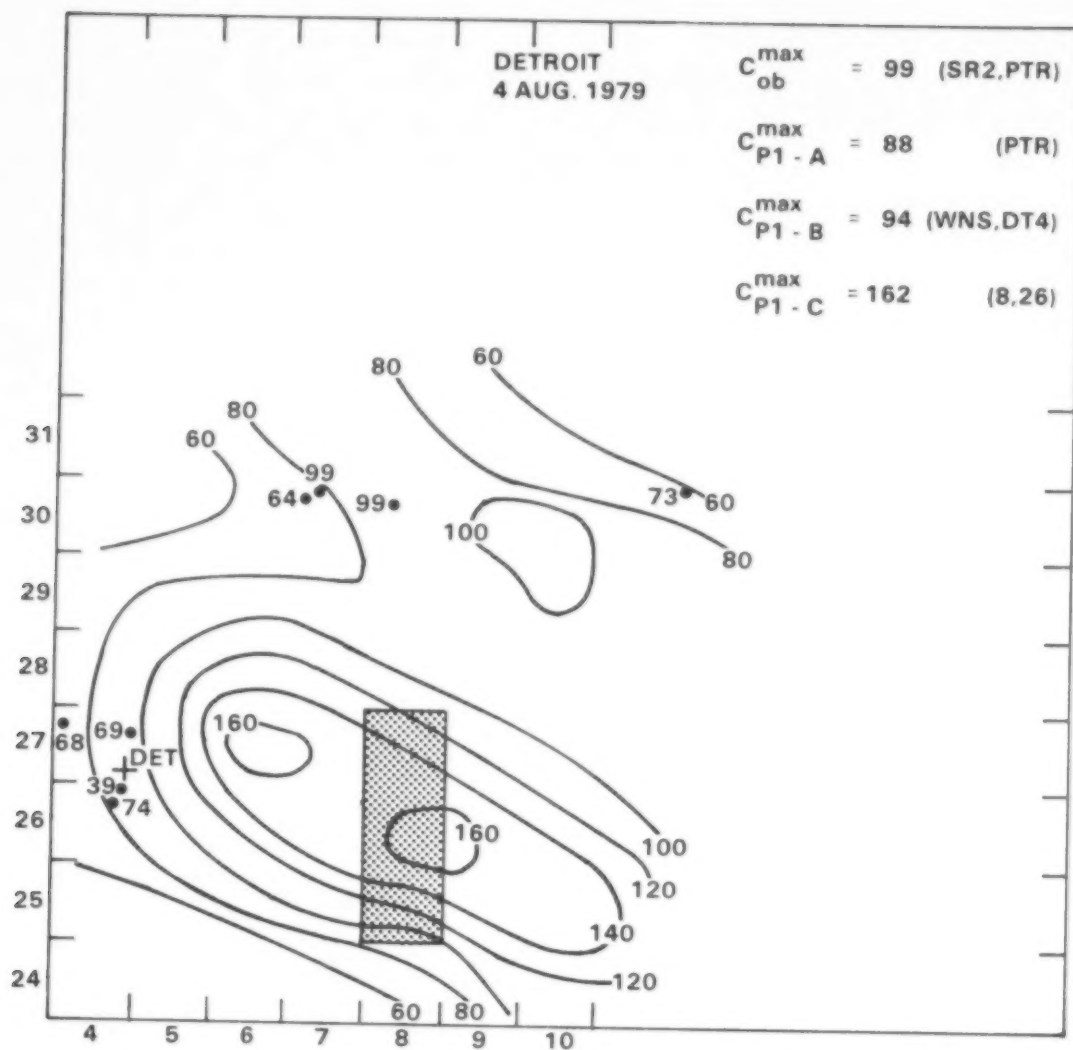


Figure 31. Predicted (ROM1 layer 1) and observed maximum  $O_3$  concentrations (ppb) downwind of Detroit on 4 Aug. 1979.

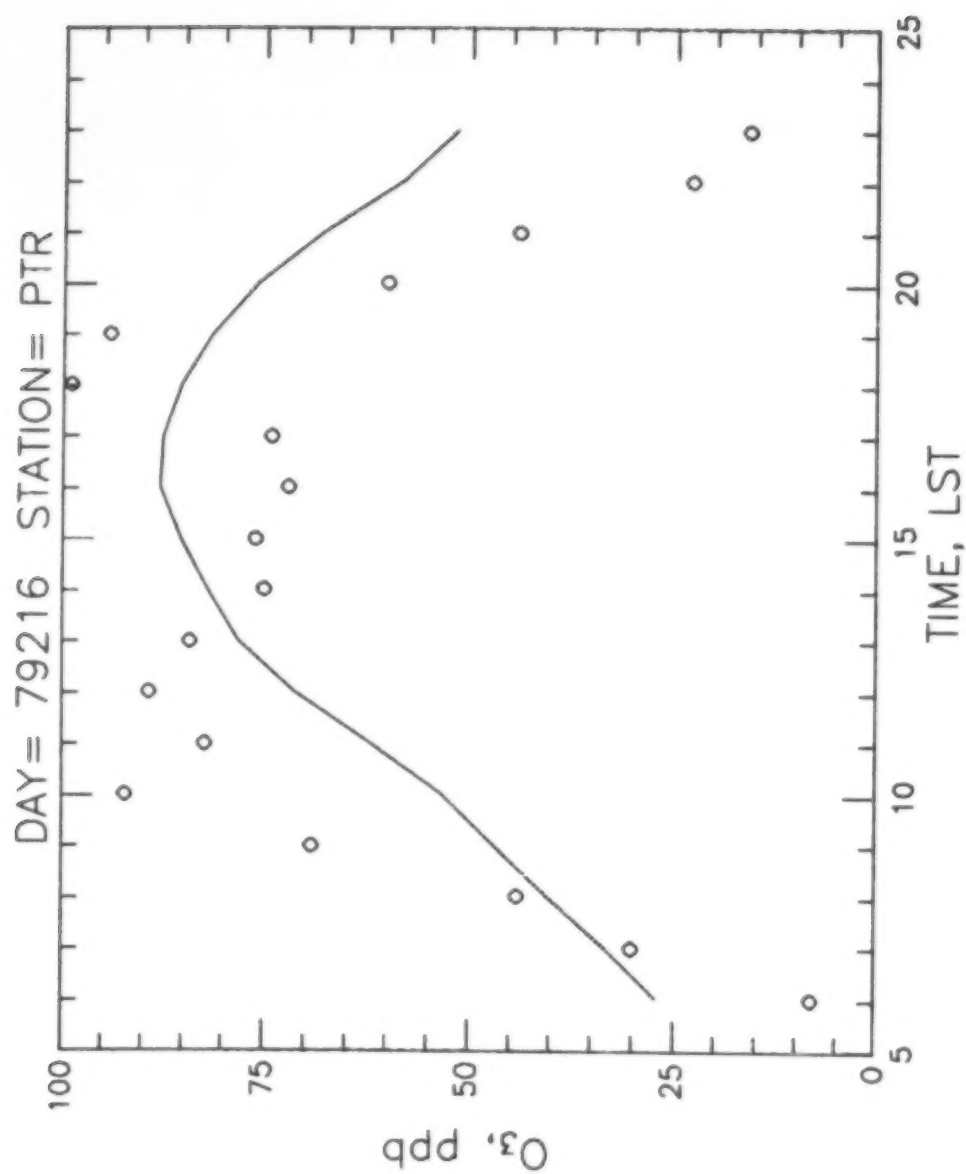


Figure 32. Time-series of predicted (ROM1 layer 1) and observed O<sub>3</sub> concentrations at monitoring site PTR on 4 Aug. 1979.

cells in the ROM1 model domain. The shaded cells in Figure 31 correspond to the locations where the aircraft sampled  $O_3$  above the 60 ppb background level that existed on either side of the plume. Within the shaded cells the integrated observed values along the aircraft trajectory were about 90 ppb in cell (8,25), 105 ppb in cell (8,26), and 110 ppb in cell (8,27), although individual  $O_3$  peak values within this sampling area reached 150 ppb. The model predictions and the aircraft observations are in rough agreement here in terms of plume location, width, and approximate  $O_3$  concentrations. The maximum level predicted in the model (162 ppb in grid cell 8,26) occurred at 1600 h, LST while the aircraft sampling in the vicinity occurred at 1400 h, LST.

The  $O_3$  plumes from the New York and Philadelphia areas on 4 August are shown in Figure 33. The forward trajectories for that day predict the plumes to be located SE of Philadelphia and SSE of New York. Maximum predicted  $O_3$  concentrations in those areas are 135 ppb downwind of Philadelphia and 114 ppb downwind of New York. There is also a maximum concentration area to the east of New York that is not in a downwind direction of the city. Recirculation effects from the looped trajectory out of New York on the previous day have most likely had an additive effect with fresh emissions to the north of New York on the current day to produce this maximum concentration area off Long Island. The only surface station within this predicted plume is BAB and the maximum level recorded there was 58 ppb. There is no evidence that there was, in fact, a plume in this vicinity. The meteorological conditions of clouds and showers here on 4 August also do not support the existence of a plume. The interpolated field of cloud cover however did show some anomalous areas in the data-sparse regions over the ocean and these areas may have underestimated the cloud cover to the east of New York going into the ROM1. This would lead to an overestimate of photochemical reactivity.

The surface stations showing the highest maximum hourly  $O_3$  concentrations near New York lie southwest in New Jersey. A maximum value of 144 ppb was recorded at site MER, while the maximum layer 1 prediction here was 59 ppb. Figure 34 presents the time-series of predicted and observed concentrations at this site. Either the predicted plume is badly positioned or recirculation

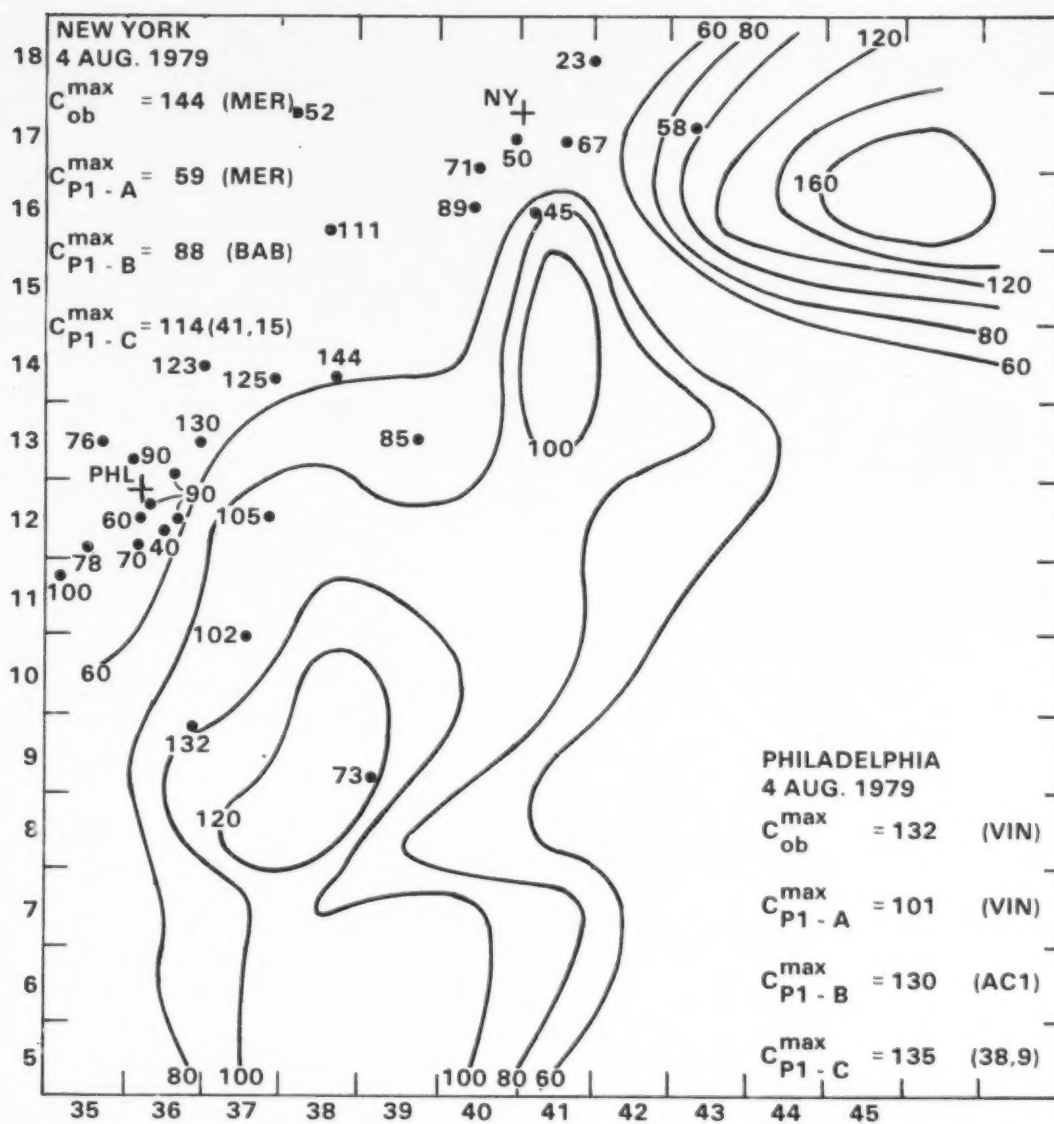


Figure 33. Predicted (ROM1 layer 1) and observed maximum  $O_3$  concentrations (ppb) downwind of New York and Philadelphia on 4 Aug. 1979.

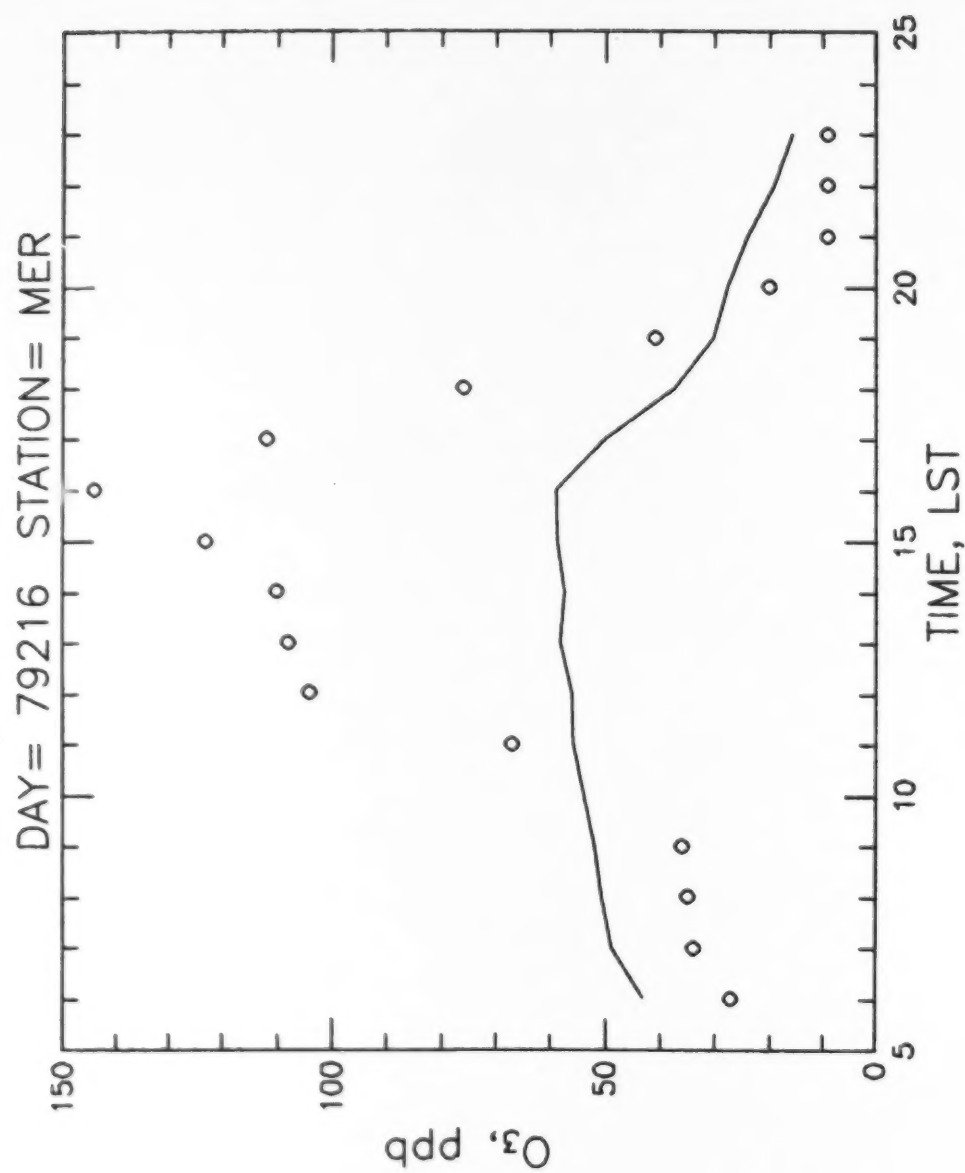


Figure 34. Time-series of predicted (ROM1 layer 1) and observed  $O_3$  concentrations at monitoring site MER on 4 Aug. 1979.

of previous day's pollutants from Philadelphia have had an effect in this area also. It is difficult to specify because of the complex wind situation existing here during the period. Evidence of recirculation also exists upwind of Philadelphia where surface stations recorded  $O_3$  maxima up to 100 ppb on 4 August. Downwind of Philadelphia surface monitors do indicate an  $O_3$  plume in the vicinity of the predicted maximum. Site VIN in south-central New Jersey recorded a maximum concentration of 132 ppb on 4 August. The relatively early hour (1300 h) at which this concentration occurred may indicate that still higher concentrations existed later in the day downwind of the site. The highest concentration predicted at VIN,  $c_{pl-A}^{max}$ , was 101 ppb, while the model predicted a maximum,  $c_{pl-C}^{max}$ , of 135 ppb at cell (38,9) less than 40 km ESE of VIN. Site AC1 is located very close to the position of the ROM1 predicted maximum and shows the highest predicted  $O_3$  maximum at a surface monitoring location,  $c_{pl-B}^{max}$ , at 130 ppb. However, the observed maximum here on 4 August was 73 ppb. Therefore, while the position of the predicted plume appears fairly good, the area of the greatest concentrations is somewhat misaligned. The time-series of predicted and observed  $O_3$  concentrations at VIN is shown in Figure 35.

Table 6 presents a summary of statistics from the global analysis of  $O_3$  plume maximum values discussed here. Seven plumes were considered, not including the Cleveland area on 3 August. The average value of  $c_{ob}^{max}$  recorded at surface monitoring sites in these plumes was 114.9 ppb. Three methods of pairing this observed value with ROM1 predictions were made. From the most restrictive to the least restrictive pairing the corresponding layer 1 model predictions averaged over the 7 cases are  $c_{pl-A}^{max} = 87.3$  ppb,  $c_{pl-B}^{max} = 106.9$  ppb, and  $c_{pl-C}^{max} = 151.0$  ppb. The last predicted value is not restricted to measurement site locations, but can be at any grid cell within the predicted plume area. This measure has the most potential for overprediction, and in fact we would expect this to be the case because the density of measurement networks is rarely sufficient to capture the true  $O_3$  peak value. The average bias for this pairing is -36.1 ppb, implying an average overprediction of about 31%. Note that the table shows the average of the normalized bias values over the individual days to be about 38%. The difference represents somewhat different

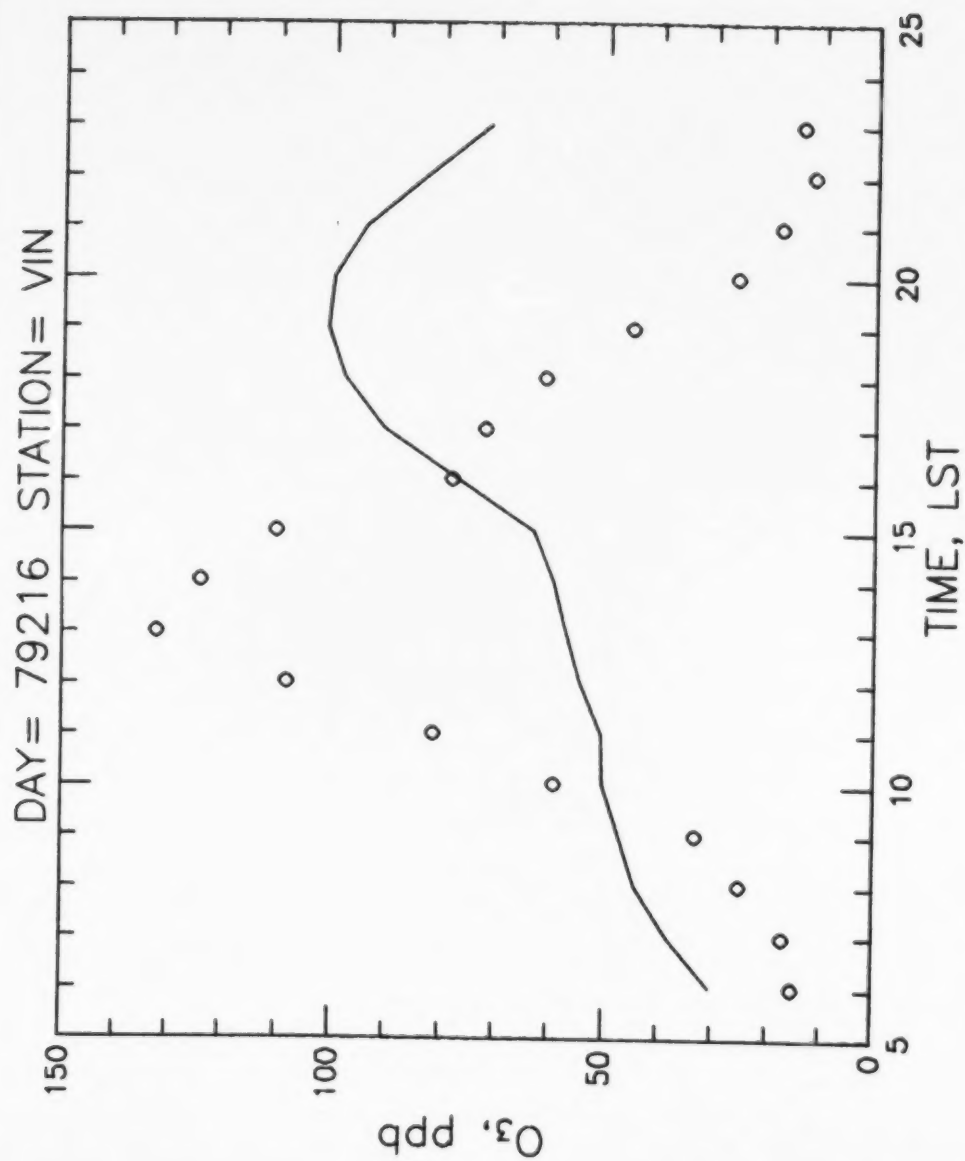


Figure 35. Time-series of predicted (ROM1 layer 1) and observed  $O_3$  concentrations at monitoring site VIN on 4 Aug. 1979.

TABLE 6. SUMMARY OF RUM1 RESULTS FOR GLOBAL MAXIMUM VALUES  
FOR 3-4 AUGUST 1979.\*

|                                            | DET<br>3 Aug    | TOR<br>3 Aug    | NY<br>3 Aug     | DET<br>4 Aug         | TOR<br>4 Aug         | NY<br>4 Aug     | PHL<br>4 Aug   | AVG   | S.D.  |
|--------------------------------------------|-----------------|-----------------|-----------------|----------------------|----------------------|-----------------|----------------|-------|-------|
| $c_{ob}^{max}$                             | 100             | 98              | 130             | 99                   | 101                  | 144             | 132            | 114.9 | 19.7  |
| (site-hr)                                  | (SR2-12)        | (ORO-16)        | (GRW-14)        | (PTR-18)             | (ORO-15)             | (MER-16)        | (VIN-13)       |       |       |
| $c_{pl-A}^{max}$                           | 90              | 110             | 97              | 88                   | 66                   | 59              | 101            | 87.3  | 18.5  |
| (site-hr)                                  | (SR2-16)        | (ORO-14)        | (GRW-15)        | (PTR-16)             | (ORO-10)             | (MER-16)        | (VIN-19)       |       |       |
| $d_{pl-A}^{max}$                           | 10              | -12             | 33              | 11                   | 35                   | 85              | 31             | 27.6  | 30.4  |
| $ d_{pl-A}^{max} $                         | 10              | 12              | 33              | 11                   | 35                   | 85              | 31             | 31.0  | 26.3  |
| $(d_{pl-A}^{max}/c_{ob}^{max}) \times 100$ | 10%             | -12.2%          | 25.4%           | 11.1%                | 34.7%                | 59%             | 23.5%          | 21.6% | 22.3% |
| $c_{pl-B}^{max}$                           | 122             | 110             | 97              | 94                   | 107                  | 88              | 130            | 106.9 | 15.2  |
| (site-hr)                                  | (LND-21)        | (ORO-14)        | (GRW-15)        | (WNS-10)<br>(DT4-10) | (STC-18)<br>(NG2-19) | (BAB-11)        | (AC1-15)       |       |       |
| $d_{pl-B}^{max}$                           | -22             | -12             | 33              | 5                    | -6                   | 56              | 2              | 8.0   | 27.3  |
| $ d_{pl-B}^{max} $                         | 22              | 12              | 33              | 5                    | 6                    | 56              | 2              | 19.4  | 19.5  |
| $(d_{pl-B}^{max}/c_{ob}^{max}) \times 100$ | -22%            | -12.2%          | 25.4%           | 5.1%                 | -5.9%                | 38.9%           | 1.5%           | 4.4%  | 21.3% |
| $c_{pl-C}^{max}$                           | 158             | 144             | 117             | 162                  | 227                  | 114             | 135            | 151.0 | 38.2  |
| (grid cell)<br>(hr)                        | (10,28)<br>(17) | (23,38)<br>(17) | (42,19)<br>(16) | (8,26)<br>(16)       | (24,35)<br>(17)      | (41,15)<br>(17) | (38,9)<br>(15) |       |       |
| $d_{pl-C}^{max}$                           | -58             | -46             | 13              | -63                  | -126                 | 30              | -3             | -36.1 | 53.6  |
| $ d_{pl-C}^{max} $                         | 58              | 46              | 13              | 63                   | 126                  | 30              | 3              | 48.4  | 40.8  |
| $(d_{pl-C}^{max}/c_{ob}^{max}) \times 100$ | -58%            | -46.9%          | 10%             | -63.6%               | -125%                | 20.8%           | -2.3%          | -37.9 | 51.2  |

\*All concentrations are  $O_3$  (ppb); all times are hours, LST.

ways to calculate the average degree of variation of the predicted from the observed maximum value. Note that if we drop the Toronto plume on 4 August from consideration the average overprediction changes to about 23%. The very high predicted value over Lake Ontario, out of the range of the surface monitors, lends some support for this action.

The average bias in the most restrictive pairing where the model prediction is interpolated to the same location as the monitoring station is 27.6 ppb here, and the corresponding degree of underprediction is 21.6%. For the middle case, where the maximum model prediction is restricted to monitoring site locations in or near the  $O_3$  plume, but not necessarily at the site of the observed maximum, the average bias is 8.0 ppb with a corresponding degree of underprediction of 4.4%.

The variance in the values of over- or underprediction among the 7 plume cases considered is indicated by the standard deviation (s.d.) about the average. For the 2 most restrictive pairings the s.d. is about the same in each case, 21-22%. For the least restrictive pairing the s.d. is about 54%, although much of that variance is attributable to the 4 August Toronto plume case. Although layer 0 predicted values were not considered in the global maximum values analysis the results would not have been very different from those shown for layer 1. The layer 0 predicted maximum values were typically only a few ppb less than the corresponding layer 1 values.

## SECTION 4

### SUMMARY AND CONCLUSIONS

The first generation Environmental Protection Agency Regional Oxidant Model (ROM1) has been evaluated for  $O_3$  concentrations using the 2-day test period, 3-4 August 1979, from the NEROS data base. Relatively high  $O_3$  concentrations were measured at the surface and aloft during this period near the Great Lakes area of the United States and southern Ontario. Cloudy and showery conditions along the immediate East coast held  $O_3$  production to low levels except for isolated times and locations in the period. The highest measured surface  $O_3$  values were about 160 ppb south of Lake Erie on 3 August. Aircraft monitoring also confirmed about the same concentration levels aloft late on that day. An earlier study (Clarke and Ching, 1983) indicated that this large area of  $O_3$  over the Great Lakes probably had its genesis earlier than 3 August west of the NEROS region.

The ROM1 was initialized with a chemically equilibrated mix of tropospheric background species concentrations, including about 40 ppb of  $O_3$ . The rationale behind the clean initialization was that the model would start simulation sufficiently ahead of the time of prime interest so that source emissions within the model domain would have time to accumulate and participate in photochemical smog reactions producing  $O_3$ . A relatively long lead time is required with this methodology. We have used 6 hours in this 2-day test episode, but 24-48 hours of lead time would be preferable in a longer period of simulation. This lead time is a buffer during which the initial conditions are advected out of the system and model results more properly reflect the outcome of physical and chemical processes occurring within the model domain. The purpose of this is to minimize the effect of initial conditions on model results and allow us to initialize with a spatially homogeneous field of background concentrations. If this were not the case, an initial concentration field accurately reflecting the existing ambient concentrations would need to be established. This is a particularly difficult task to accomplish on the regional scale with relatively sparse data observations.

In retrospect, the 2-day episode modeled here was not long enough to justify initialization with clean conditions. Apparently the aged O<sub>3</sub> plume existing in the western model domain at the start of model simulation, but not represented in the initial concentration field, caused the ROM1 to overlook a major contribution to the high concentrations observed in the southern Great Lakes area during the first day of simulation. This preliminary model evaluation exercise is therefore more a test of the procedures that will be used in later evaluations of the second generation model, ROM2, than it is of the ability of the current model to accurately simulate plumes of O<sub>3</sub> on the regional scale. Future evaluations will simulate over an extended period of time (up to 4 weeks), circumventing the initial condition problem.

The evaluation of ROM1 on the test episode proceeded in two stages. First, an overall analysis of O<sub>3</sub> observations and predictions at receptor monitoring locations in the model domain was made for all hours of the simulation except the first six. Next an analysis of the model to predict daily maximum values of O<sub>3</sub> was performed. In the first stage where all data were involved, results showed that the ROM1 predictions averaged under 6% less than measurements at monitoring sites. There is, however not much significance to this result since averaging data over all monitoring stations for all hours weights the result near the tropospheric background level. We are more concerned with the model's ability to predict higher values of O<sub>3</sub>. Therefore in a second part to the first stage of analysis the same manner of evaluation was applied to a subset of the data where only simultaneous O<sub>3</sub> values above 50 ppb were included for observed and predicted concentrations at monitoring sites. In this case the average observed O<sub>3</sub> concentration over all receptors and hours was 72.2 ppb, above the level of general background O<sub>3</sub>. The average ROM1 performance for the data subset showed a 4.6% underprediction for layer 0 and a 1.4% underprediction for layer 1. Beyond these averaged statistics, the graphical analyses used in interpreting model evaluation results were extremely useful. These analyses included histograms of observed, predicted, and residual data as well as time series of the model bias. The inherent structure of the data as well as trends in model bias can be seen from these type plots.

The second stage of model evaluation, using daily O<sub>3</sub> maxima, also proceeded in 2 steps. In the first step the daily maximum value at each receptor location was compared to the predicted maximum at that location as well as the prediction at the same time as the observed maximum. For layer 1, the ROM1 performance showed an average 31% underprediction for the first comparison and a 43% underprediction for the second comparison. Results for layer 0 were similar. When data were restricted to those observed and predicted O<sub>3</sub> pairs above 50 ppb the model performance for the local maximum analysis improved by showing average underpredictions of 8% and 15%, respectively for the above layer 1 comparisons. The improvement in model predictions in this case is principally due to restricting the analysis to comparisons at monitoring station locations where source emissions had a larger effect on O<sub>3</sub> levels than material that was present initially and overlooked by the clean initialization procedure.

The second step of evaluating the ROM1's performance for O<sub>3</sub> maxima predictions involves an analysis of individual plumes of O<sub>3</sub> from major source areas within the NEROS region. This is perhaps the most challenging and potentially, the most rewarding aspect of the model evaluation for it addresses the major aspect of the regional model's function, resolving plumes of pollution from urban scale and smaller sources on a regional scale grid. A difficult aspect of this step in the evaluation is determining the location and magnitude of the source plumes from a monitoring network that was not designed specifically for regional scale purposes. Monitors are most often located close to urban areas and downwind spatial coverage is usually very limited. Nevertheless, 7 cases of such plumes were identified and analyzed for the 3-4 August 1979 episode. The evaluation used three types of comparisons of O<sub>3</sub> maxima; only layer 1 model predictions were considered in this part of the analysis. The first comparison matched the observed daily maximum O<sub>3</sub> level at any monitoring site within a plume with the daily maximum O<sub>3</sub> prediction at that site. The second comparison matched the observed O<sub>3</sub> maximum with the predicted maximum at any site within or near the plume, and the third comparison matched the observed maximum with the predicted maximum at any grid cell within or near the plume. Results averaged over the 7

plumes in the test case showed a 22% underprediction for the first comparison, a 4% underprediction for the second comparison, and a 38% overprediction for the third comparison. In interpreting these results one must bear in mind that the monitoring network is probably not sufficiently dense to capture the actual ambient maximum  $O_3$  value within a plume, and also the predicted plume location and magnitudes of  $O_3$  may not be quite accurate.

There are numerous reasons why the ROM1 may not have performed well for a given plume. We have already discussed the fact that the model was initialized with precursor species concentrations considerably below ambient conditions for some areas of the grid. Another condition likely to cause problems in model performance is a wind field with poorly defined organization. This can lead to large uncertainties in the transport and dispersion of a plume. A third condition under which the ROM1 may perform poorly is that of "patchy" cloudiness, or large spatial variability in cloud cover. This condition has the potential for calculated errors in the amount of sunlight available to the photochemical precursor species for  $O_3$  formation. Examining the ROM1 performance for  $O_3$  in light of these 3 conditions may provide an interesting perspective.

Both the surface data and aircraft sampling have shown that the location and magnitude of the predicted  $O_3$  plume from Detroit on 4 Aug. is fairly accurate. The wind field in this part of the domain is well-organized with a predominant flow from the WNW during the early part of the day, shifting to more westerly and WSW directions later. Likewise, the skies were mostly clear throughout this part of the simulation period here. An examination of the ambient concentration levels of  $O_3$  and precursor species on 2 Aug. near and upwind of Detroit does not show the presence of high concentration levels, indicating that the assumption of clean tropospheric initial concentrations was probably not in gross error. We might speculate then that the good performance of ROM1 in this case is not due to chance, but rather because certain identifiable physical conditions that are associated with the likelihood of consistent model behavior have been met. The concurrent aircraft sampling of  $O_3$  in this plume with high levels of photochemical activity

provides a definitive measure of the model performance. Similar conditions of steady flow and mostly clear skies also existed with the Detroit plume of 3 Aug. and the Toronto plumes on both days. Model performance for  $O_3$  in these plumes was also quite good at the monitoring station locations.

The flow field along the East coast was much less organized during the period than it was in the Great Lakes area because of the presence of a stationary front. Highly variable cloud cover was also seen to exist there. The rather poor performance of the model in the vicinity of the New York plume on 4 Aug. is not surprising in view of this. The predicted plume location and magnitude is not supported by any of the monitoring data. Model performance for the New York plume on 3 Aug. is mixed, with apparently reasonable agreement to the northeast in Connecticut and poor performance to the south and southwest. The looping trajectory of this plume, shown in Figure 19, indicates some of the disorganization of the flow. The fairly good agreement shown between  $O_3$  observations and predictions in the Philadelphia plume on 4 Aug. is one case that may be ascribed to chance as several of the conditions described above associated with potentially poor model performance were in effect. Also, model performance for  $O_3$  was seen to be poor for the first day of simulation where heavier  $O_3$  or precursor concentrations were relatively high on 2 Aug., such as to the south of Lake Erie, between Cleveland, OH and Erie, PA and also on the East coast between New York and Philadelphia.

Overall, the performance of ROM1 for  $O_3$  on this test episode is quite good. Judging from the performance of the model in the vicinity of the analyzed  $O_3$  plumes for maximum  $O_3$  concentrations the model performance is within the range of 4-22% underprediction, corresponding to the 2 stricter methods of paired comparison between model prediction and observation. The least strict pairing is more appropriate for a denser monitoring network, but it is useful for examining the full predictive photochemical potential from a source emissions region. The model results for prediction of maximum  $O_3$  at receptor sites where both the observed and predicted values were over 50 ppb were also quite good, in the range of 3-15% underprediction. These are the sites most likely to have been affected by plumes generated from emissions sources within the model domain.

In summary, the ROM1 performed well and in a consistent pattern in areas of the domain least affected by high boundary or initial species concentrations, by large spatial gradients in meteorological factors, and in areas most affected by large emissions source areas within the domain. Applications with the second generation regional model, ROM2, will address some of the deficiencies found with this test application of the ROM1. The ROM2 applications will begin at a time of relatively clean conditions throughout the model domain so the assumption of clean tropospheric conditions will be fair. Also the simulation period will be one of several weeks duration to minimize the impact of the initial conditions. The probabilistic capability of the model's wind field processor will be explored in the ROM2 evaluation. This capability may address some of the concerns about model performance in regions of less organized flow.

The ROM2 will also incorporate a newer and more complete chemical kinetic mechanism than ROM1 allowing it to include biogenic organic species in the emissions inventory, a possibly important component in the photochemical smog equation on the regional scale. The vertical depth of the grid cells in ROM2 will be variable in space and time and will respond to the physical phenomena influencing the depth and stability of the boundary layer. Terrain features and cell-specific cloud fluxes will be more accurately treated. The ability of ROM2 to estimate sub-grid scale concentration fluctuations near the surface will be explored. Current plans include modeling approximately 4 weeks from the summer 1980 period of the NEROS and SAROAD data bases.

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## APPENDIX A

### LISTING OF SURFACE MONITORING STATIONS

This appendix contains a list of all surface monitoring sites for  $O_3$  in the SAROAD and NEROS programs that were in operation during any part of 1979 and 1980. Ontario (Canada) sites are also included. The listing is limited to those sites within and just outside of the ROM modeling domain for the NEROS application. Site locations are listed both by latitude-longitude and grid coordinates.

| SITE | LOCATION        | STATE OR<br>PROVINCE | LATITUDE<br>(deg, N) | LONGITUDE<br>(deg, W) | X-GRID           | Y-GRID |
|------|-----------------|----------------------|----------------------|-----------------------|------------------|--------|
| AA1  | ANNE ARUNDEL CO | MD                   | 39.21                | 76.65                 | 29.4             | 7.3    |
| AA2  | ANNE ARUNDEL CO | MD                   | 39.17                | 76.63                 | 29.5             | 7.0    |
| AA3  | ANNE ARUNDEL CO | MD                   | 38.90                | 76.65                 | 29.4             | 5.4    |
| AA4  | ANNE ARUNDEL CO | MD                   | 39.10                | 76.73                 | 29.1             | 6.6    |
| AC1  | ATLANTIC CO     | NJ                   | 39.52                | 74.46                 | 38.2             | 9.1    |
| AC2  | ATLANTIC CITY   | NJ                   | 39.36                | 74.44                 | 38.2             | 8.1    |
| AG1  | ALLEGHENY CO    | PA                   | 40.38                | 80.19                 | 15.3             | 14.3   |
| AG2  | ALLEGHENY CO    | PA                   | 40.44                | 79.95                 | 16.2             | 14.6   |
| AG3  | ALLEGHENY CO    | PA                   | 40.44                | 79.99                 | 16.0             | 14.7   |
| AG4  | ALLEGHENY CO    | PA                   | 40.47                | 79.82                 | 16.7             | 14.8   |
| AGA  | AGAWAM          | MA                   | 42.04                | 72.64                 | 45.5             | 24.2   |
| AK1  | AKRON           | OH                   | 41.08                | 81.52                 | 9.9              | 18.5   |
| AK2  | AKRON           | OH                   | 41.11                | 81.50                 | 10.0             | 18.6   |
| ALC  | ALLEN CO        | OH                   | 40.76                | 84.07                 | OUTSIDE ROM GRID |        |
| ALN  | ALLENTOWN       | PA                   | 40.62                | 75.45                 | 34.2             | 15.7   |
| ALP  | ALLEN PARK      | MI                   | 42.23                | 83.21                 | 3.2              | 25.4   |
| ALT  | ALTOONA         | PA                   | 40.51                | 78.39                 | 22.4             | 15.1   |
| ALX  | ALEXANDRIA      | VA                   | 38.81                | 77.04                 | 27.8             | 4.9    |
| AMH  | AMHERST         | NY                   | 42.99                | 78.78                 | 20.9             | 30.0   |
| AMR  | AMHERST         | MA                   | 42.39                | 72.52                 | 45.9             | 26.3   |
| ARL  | ARLINGTON CO    | VA                   | 38.86                | 77.06                 | 27.8             | 5.1    |
| AS1  | ASHLAND         | KY                   | 38.44                | 82.61                 | 5.5              | 2.7    |
| AS2  | ASHLAND         | KY                   | 38.48                | 82.52                 | 5.9              | 2.9    |
| AS3  | ASHLAND         | KY                   | 38.46                | 82.64                 | 5.4              | 2.8    |
| ASB  | ASBURY PARK     | NJ                   | 40.22                | 74.01                 | 39.9             | 13.3   |
| ATL  | ATTLEBORO       | MA                   | 41.93                | 71.26                 | 50.9             | 23.6   |
| BAB  | BABYLON         | NY                   | 40.74                | 73.41                 | 42.4             | 16.4   |
| BAC  | BAY COUNTY      | MI                   | 43.64                | 83.85                 | 0.6              | 33.9   |
| BAD  | BADEN           | PA                   | 40.64                | 80.23                 | 15.1             | 15.8   |
| BAR  | BARBERTON       | OH                   | 41.00                | 81.63                 | 9.5              | 18.0   |
| BAY  | BAYONNE         | NJ                   | 40.68                | 74.12                 | 39.5             | 16.1   |
| BC1  | BOONE CO        | KY                   | 38.92                | 84.85                 | OUTSIDE ROM GRID |        |
| BC2  | BOONE CO        | KY                   | 39.05                | 84.88                 | OUTSIDE ROM GRID |        |
| BCK  | BRACKENRIDGE    | PA                   | 40.61                | 79.75                 | 17.0             | 15.7   |
| BER  | BEREA           | OH                   | 41.37                | 81.85                 | 8.6              | 20.2   |
| BET  | BETHLEHEM       | PA                   | 40.62                | 75.36                 | 34.5             | 15.7   |
| BF1  | BUFFALO         | NY                   | 42.88                | 78.81                 | 20.8             | 29.3   |
| BF2  | BUFFALO         | NY                   | 42.93                | 78.87                 | 20.5             | 29.6   |
| BF3  | BUFFALO         | NY                   | 42.89                | 78.89                 | 20.4             | 29.3   |
| BGR  | BANGOR          | ME                   | 44.80                | 68.77                 | OUTSIDE ROM GRID |        |
| BL1  | BALTIMORE       | MD                   | 39.30                | 76.61                 | 29.5             | 7.8    |
| BL2  | BALTIMORE       | MD                   | 39.24                | 76.58                 | 29.7             | 7.4    |
| BL3  | BALTIMORE       | MD                   | 39.31                | 76.61                 | 29.5             | 7.9    |
| BL4  | BALTIMORE       | MD                   | 39.29                | 76.63                 | 29.5             | 7.7    |
| BL5  | BALTIMORE       | MD                   | 39.29                | 76.61                 | 29.6             | 7.7    |
| BL6  | BALTIMORE CO    | MD                   | 39.41                | 76.77                 | 28.9             | 8.4    |
| BL7  | BALTIMORE CO    | MD                   | 39.51                | 76.43                 | 30.3             | 9.1    |
| BLG  | BURLINGTON      | ON                   | 43.32                | 79.80                 | 16.8             | 31.9   |
| BN1  | BERLIN          | NH                   | 44.48                | 71.18                 | 51.3             | 38.9   |
| BN2  | BERLIN          | NH                   | 44.47                | 71.18                 | 51.3             | 38.8   |

| SITE | LOCATION          | STATE OR<br>PROVINCE | LATITUDE<br>(deg, N) | LONGITUDE<br>(deg, W) | X-GRID           | Y-GRID |
|------|-------------------|----------------------|----------------------|-----------------------|------------------|--------|
| BNG  | BINGHAMTON        | NY                   | 42.10                | 75.89                 | 32.4             | 24.6   |
| BNW  | BINBROOK WEST     | ON                   | 43.12                | 79.88                 | 16.5             | 30.7   |
| BR1  | BRIDGEPORT        | CT                   | 41.18                | 73.19                 | 43.2             | 19.1   |
| BR2  | BRIDGEPORT        | CT                   | 41.19                | 73.18                 | 43.3             | 19.1   |
| BRI  | BRISTOL (BOROUGH) | PA                   | 40.25                | 75.00                 | 36.0             | 13.5   |
| BRL  | BURLINGTON        | NJ                   | 40.08                | 74.86                 | 36.6             | 12.5   |
| BS1  | BOSTON            | MA                   | 42.35                | 71.10                 | 51.6             | 26.1   |
| BS2  | BOSTON            | MA                   | 42.37                | 71.04                 | 51.8             | 26.2   |
| BS3  | BOSTON            | MA                   | 42.38                | 71.03                 | 51.9             | 26.3   |
| BS4  | BOSTON            | MA                   | 42.35                | 71.06                 | 51.7             | 26.1   |
| BTH  | BETHESDA          | MD                   | 39.00                | 77.11                 | 27.6             | 6.0    |
| BU1  | BURLINGTON        | VT                   | 44.48                | 73.21                 | 43.2             | 38.9   |
| BU2  | BURLINGTON        | VT                   | 44.46                | 73.19                 | 43.2             | 38.7   |
| BUL  | BURLINGTON CO.    | NJ                   | 39.96                | 74.79                 | 36.8             | 11.8   |
| BUT  | BUTLER CO         | PA                   | 41.01                | 79.72                 | 17.1             | 18.0   |
| BVF  | BEAVER FALLS      | PA                   | 40.75                | 80.32                 | 14.7             | 16.5   |
| CAN  | CANTON            | OH                   | 40.80                | 81.38                 | 10.5             | 16.8   |
| CAR  | CARIBOU           | ME                   | 46.87                | 68.01                 | OUTSIDE ROM GRID |        |
| CB1  | COLUMBUS          | OH                   | 40.00                | 83.04                 | 3.8              | 12.0   |
| CB2  | COLUMBUS          | OH                   | 40.06                | 82.98                 | 4.1              | 12.4   |
| CB3  | COLUMBUS          | OH                   | 39.96                | 82.99                 | 4.0              | 11.8   |
| CB4  | COLUMBUS          | OH                   | 39.96                | 82.99                 | 4.0              | 11.8   |
| CB5  | COLUMBUS          | OH                   | 40.09                | 82.96                 | 4.2              | 12.5   |
| CBN  | CARBONDALE        | PA                   | 41.57                | 75.51                 | 34.0             | 21.4   |
| CCL  | CECIL CO          | MD                   | 39.72                | 76.11                 | 31.6             | 10.3   |
| CHL  | CHARLEROI         | PA                   | 40.15                | 79.90                 | 16.4             | 12.9   |
| CHP  | CHESAPEAKE        | VA                   | 36.67                | 76.33                 | OUTSIDE ROM GRID |        |
| CHR  | CHARLTON          | MA                   | 42.31                | 71.97                 | 48.1             | 25.9   |
| CHS  | CHARLESTON        | WV                   | 38.34                | 81.62                 | 9.5              | 2.1    |
| CHT  | CHESTER           | PA                   | 39.84                | 75.37                 | 34.5             | 11.0   |
| CHV  | CHEVERLY          | MD                   | 38.92                | 76.90                 | 28.4             | 5.5    |
| CKY  | COCKEYSVILLE      | MD                   | 39.46                | 76.63                 | 29.5             | 8.8    |
| CL1  | CLEVELAND         | OH                   | 41.50                | 81.62                 | 9.5              | 21.0   |
| CL2  | CLEVELAND         | OH                   | 41.55                | 81.57                 | 9.7              | 21.3   |
| CLK  | CLARK CO          | OH                   | 40.00                | 83.80                 | 0.8              | 12.0   |
| CLN  | CLINTON CO        | OH                   | 39.43                | 83.79                 | 0.9              | 8.6    |
| CLO  | CALLOWAY CO       | KY                   | 36.73                | 88.12                 | OUTSIDE ROM GRID |        |
| CLR  | CLERMONT CO       | OH                   | 39.08                | 84.18                 | OUTSIDE ROM GRID |        |
| CM1  | CAMDEN            | NJ                   | 39.92                | 75.10                 | 35.6             | 11.5   |
| CM2  | CAMDEN            | NJ                   | 39.95                | 75.12                 | 35.5             | 11.7   |
| CM3  | CAMDEN CO         | NJ                   | 39.67                | 74.86                 | 36.6             | 10.0   |
| CMB  | CUMBERLAND        | MD                   | 39.65                | 78.76                 | 20.9             | 9.9    |
| CN1  | CINCINNATI        | OH                   | 39.14                | 84.55                 | OUTSIDE ROM GRID |        |
| CN2  | CINCINNATI        | OH                   | 39.21                | 84.48                 | OUTSIDE ROM GRID |        |
| CN3  | CINCINNATI        | OH                   | 39.14                | 84.51                 | OUTSIDE ROM GRID |        |
| CNE  | CONNEAUT          | OH                   | 41.96                | 80.57                 | 13.7             | 23.8   |
| CNS  | CONSHOHOCKEN      | PA                   | 40.07                | 75.30                 | 34.8             | 12.4   |
| CPE  | CAPE ELIZABETH    | ME                   | 43.57                | 70.20                 | 55.2             | 33.4   |
| CPM  | CAPE MAY CO       | NJ                   | 39.10                | 74.82                 | 36.7             | 6.6    |

| SITE | LOCATION        | STATE OR<br>PROVINCE | LATITUDE<br>(deg, N) | LONGITUDE<br>(deg, W) | X-GRID  | Y-GRID   |
|------|-----------------|----------------------|----------------------|-----------------------|---------|----------|
| CR1  | CORUNNA         | ON                   | 42.88                | 82.45                 | 6.2     | 29.3     |
| CR3  | CORUNNA         | ON                   | 42.91                | 82.45                 | 6.2     | 29.5     |
| CTF  | CHESTERFIELD CO | VA                   | 37.36                | 77.59                 | OUTSIDE | ROM GRID |
| CUM  | CUMBERLAND CO   | ME                   | 43.91                | 70.23                 | 55.1    | 35.5     |
| CV1  | COVINGTON       | KY                   | 39.07                | 84.53                 | OUTSIDE | ROM GRID |
| CV2  | COVINGTON       | KY                   | 39.09                | 84.51                 | OUTSIDE | ROM GRID |
| DA1  | DAYTON          | OH                   | 39.77                | 84.21                 | OUTSIDE | ROM GRID |
| DA2  | DAYTON          | OH                   | 39.76                | 84.19                 | OUTSIDE | ROM GRID |
| DA3  | DAYTON          | OH                   | 39.81                | 84.19                 | OUTSIDE | ROM GRID |
| DA4  | DAYTON          | OH                   | 39.76                | 84.20                 | OUTSIDE | ROM GRID |
| DA5  | DAYTON          | OH                   | 39.78                | 84.20                 | OUTSIDE | ROM GRID |
| DAN  | DANBURY         | CT                   | 41.40                | 73.44                 | 42.2    | 20.4     |
| DAY  | DAYTON          | KY                   | 39.11                | 84.48                 | OUTSIDE | ROM GRID |
| DC1  | WASHINGTON      | DC                   | 38.90                | 77.05                 | 27.8    | 5.4      |
| DC2  | WASHINGTON      | DC                   | 38.98                | 77.02                 | 27.9    | 5.9      |
| DC3  | WASHINGTON      | DC                   | 38.89                | 77.01                 | 27.9    | 5.3      |
| DC4  | WASHINGTON      | DC                   | 38.88                | 76.97                 | 28.1    | 5.3      |
| DC5  | WASHINGTON      | DC                   | 38.93                | 77.06                 | 27.8    | 5.6      |
| DC6  | WASHINGTON      | DC                   | 38.94                | 77.03                 | 27.9    | 5.7      |
| DMS  | DAMASCUS        | MD                   | 39.27                | 77.22                 | 27.1    | 7.6      |
| DNR  | DONORA          | PA                   | 40.17                | 79.86                 | 16.5    | 13.0     |
| DNV  | DANVILLE        | KY                   | 37.67                | 84.77                 | OUTSIDE | ROM GRID |
| DOV  | DOVER           | DE                   | 39.15                | 75.50                 | 34.0    | 6.9      |
| DOW  | DOWNINGTON      | PA                   | 40.02                | 75.71                 | 33.2    | 12.1     |
| DRB  | DERBY           | CT                   | 41.32                | 73.09                 | 43.6    | 19.9     |
| DT1  | DETROIT         | MI                   | 42.40                | 83.24                 | 3.1     | 26.4     |
| DT2  | DETROIT         | MI                   | 42.36                | 83.10                 | 3.6     | 26.1     |
| DT3  | DETROIT         | MI                   | 42.43                | 83.00                 | 4.0     | 26.6     |
| DT4  | DETROIT         | MI                   | 42.33                | 83.03                 | 3.9     | 26.0     |
| DT5  | DETROIT         | MI                   | 42.33                | 83.05                 | 3.3     | 26.0     |
| DUM  | DUMONT          | NJ                   | 40.94                | 74.00                 | 40.0    | 17.6     |
| DVR  | DANVERS         | MA                   | 42.59                | 70.98                 | 52.1    | 27.6     |
| EAS  | EASTON          | PA                   | 40.68                | 75.22                 | 35.1    | 16.1     |
| EB1  | ETOBICOKE       | ON                   | 43.65                | 79.58                 | 17.7    | 33.9     |
| EB2  | ETOBICOKE       | ON                   | 43.62                | 79.52                 | 17.9    | 33.7     |
| EDG  | EDGEWOOD        | MD                   | 39.41                | 76.30                 | 30.8    | 8.5      |
| ELM  | ELMIRA          | NY                   | 42.11                | 76.80                 | 28.8    | 24.7     |
| ENF  | ENFIELD         | CT                   | 42.00                | 72.57                 | 45.7    | 24.0     |
| ERE  | ERIE            | PA                   | 42.14                | 80.05                 | 15.8    | 24.8     |
| ESO  | EAST ORANGE     | NJ                   | 40.76                | 74.20                 | 39.2    | 16.5     |
| ESS  | ESSEXVILLE      | MI                   | 43.62                | 83.85                 | 0.6     | 33.7     |
| EST  | EASTON          | MA                   | 42.07                | 71.09                 | 51.6    | 24.4     |
| ESX  | ESSEX           | MD                   | 39.35                | 76.48                 | 30.1    | 8.1      |
| EXC  | ESSEX CO        | NY                   | 44.37                | 73.90                 | 40.4    | 38.2     |
| EY1  | ELYRIA          | OH                   | 41.37                | 82.11                 | 7.6     | 20.2     |
| EY2  | ELYRIA          | OH                   | 41.37                | 82.11                 | 7.6     | 20.2     |
| EZ1  | ELIZABETH       | NJ                   | 40.66                | 74.21                 | 39.1    | 16.0     |
| EZ2  | ELIZABETH       | NJ                   | 40.64                | 74.21                 | 39.2    | 15.8     |
| FAY  | FAYETTE CO      | KY                   | 38.13                | 84.47                 | OUTSIDE | ROM GRID |

| SITE | LOCATION            | STATE OR<br>PROVINCE | LATITUDE<br>(deg, N) | LONGITUDE<br>(deg, W) | X-GRID  | Y-GRID   |
|------|---------------------|----------------------|----------------------|-----------------------|---------|----------|
| FDR  | FREDERICKSBURG      | VA                   | 38.31                | 77.45                 | 26.2    | 1.9      |
| FLM  | FLEMINGTON          | NJ                   | 40.52                | 74.81                 | 36.8    | 15.1     |
| FLN  | FLINT               | MI                   | 43.02                | 83.69                 | 1.3     | 30.1     |
| FLO  | FLORENCE            | KY                   | 39.00                | 84.63                 | OUTSIDE | ROM GRID |
| FOL  | FOLCROFT            | PA                   | 39.89                | 75.28                 | 34.9    | 11.3     |
| FRD  | FREDERICK CO        | MD                   | 39.48                | 77.23                 | 27.1    | 8.9      |
| FRE  | FREEHOLD            | NJ                   | 40.26                | 74.27                 | 38.9    | 13.6     |
| FX1  | FAIRFAX             | VA                   | 38.84                | 77.31                 | 26.8    | 5.1      |
| FX2  | FAIRFAX CO          | VA                   | 38.73                | 77.10                 | 27.6    | 4.4      |
| FX3  | FAIRFAX CO          | VA                   | 38.74                | 77.08                 | 27.7    | 4.5      |
| GAR  | GARDNER             | MA                   | 42.57                | 71.99                 | 48.0    | 27.4     |
| GLN  | GLENS FALLS         | NY                   | 43.32                | 73.62                 | 41.5    | 31.9     |
| GLO  | GLOUCESTER          | MA                   | 42.62                | 70.71                 | 53.2    | 27.7     |
| GMT  | GREEN MOUNTAIN NAT. | VT                   | 43.93                | 73.03                 | 43.9    | 35.6     |
| GNB  | GREENBRIER CO       | WV                   | 37.77                | 80.33                 | OUTSIDE | ROM GRID |
| GNS  | GENESEE CO          | MI                   | 43.17                | 83.46                 | 2.2     | 31.0     |
| GRD  | GARDINER            | ME                   | 44.22                | 69.79                 | 56.8    | 37.3     |
| GRE  | GREENFIELD          | MA                   | 42.57                | 72.60                 | 45.6    | 27.4     |
| GRG  | GEORGETOWN          | MA                   | 42.72                | 70.99                 | 52.1    | 28.3     |
| GRN  | GREENBELT           | MD                   | 39.02                | 76.83                 | 28.7    | 6.1      |
| GRR  | GRAND RAPIDS        | MI                   | 42.97                | 85.68                 | OUTSIDE | ROM GRID |
| GRW  | GREENWICH           | CT                   | 41.08                | 73.71                 | 41.2    | 18.5     |
| HAK  | HACKENSACK          | NJ                   | 40.88                | 74.04                 | 39.8    | 17.3     |
| HAM  | HAMILTON            | MA                   | 42.63                | 70.82                 | 52.7    | 27.8     |
| HAR  | HARRISBURG          | PA                   | 40.24                | 76.85                 | 28.6    | 13.5     |
| HEN  | HENRICO CO          | VA                   | 37.59                | 77.42                 | OUTSIDE | ROM GRID |
| HF1  | HARTFORD            | CT                   | 41.77                | 72.68                 | 45.3    | 22.6     |
| HF2  | HARTFORD            | CT                   | 41.76                | 72.68                 | 45.3    | 22.6     |
| HGR  | HAGERSTOWN          | MD                   | 39.65                | 77.72                 | 25.1    | 9.9      |
| HM1  | HEMPSTEAD           | NY                   | 40.75                | 73.59                 | 41.7    | 16.5     |
| HM2  | HEMPSTEAD           | NY                   | 40.89                | 73.60                 | 41.6    | 17.4     |
| HML  | HAMILTON            | ON                   | 43.26                | 79.84                 | 16.6    | 31.6     |
| HMP  | HAMPTON             | VA                   | 37.00                | 76.40                 | OUTSIDE | ROM GRID |
| HN1  | HENDERSON           | KY                   | 37.86                | 87.58                 | OUTSIDE | ROM GRID |
| HN2  | HENDERSON           | KY                   | 37.88                | 87.57                 | OUTSIDE | ROM GRID |
| HNC  | HANCOCK CO          | KY                   | 37.94                | 86.90                 | OUTSIDE | ROM GRID |
| HNR  | HENRICO CO          | VA                   | 37.59                | 77.50                 | OUTSIDE | ROM GRID |
| HNV  | HANOVER CO          | VA                   | 37.64                | 77.32                 | OUTSIDE | ROM GRID |
| HOP  | HOPKINS CO          | KY                   | 37.53                | 87.35                 | OUTSIDE | ROM GRID |
| HOW  | HOWARD CO           | MD                   | 39.17                | 76.90                 | 28.4    | 7.0      |
| HRD  | HARDIN CO           | KY                   | 37.76                | 85.72                 | OUTSIDE | ROM GRID |
| HRF  | HARFORD CO          | MD                   | 39.63                | 76.33                 | 30.7    | 9.8      |
| HR0  | HARRODSBURG         | KY                   | 37.76                | 84.83                 | OUTSIDE | ROM GRID |
| HRP  | HURON PARK          | ON                   | 43.29                | 81.49                 | 10.0    | 31.7     |
| HT1  | HAMILTON CO         | OH                   | 39.28                | 84.37                 | OUTSIDE | ROM GRID |
| HT2  | HAMILTON CO         | OH                   | 39.28                | 84.37                 | OUTSIDE | ROM GRID |
| HT3  | HAMILTON CO         | OH                   | 39.16                | 84.80                 | OUTSIDE | ROM GRID |
| JF1  | JEFFERSON CO        | KY                   | 38.14                | 85.58                 | OUTSIDE | ROM GRID |
| JF2  | JEFFERSON CO        | KY                   | 38.31                | 85.58                 | OUTSIDE | ROM GRID |

| SITE | LOCATION          | STATE OR<br>PROVINCE | LATITUDE<br>(deg, N) | LONGITUDE<br>(deg, W) | X-GRID  | Y-GRID   |
|------|-------------------|----------------------|----------------------|-----------------------|---------|----------|
| JF3  | JEFFERSON CO      | KY                   | 38.11                | 85.87                 | OUTSIDE | ROM GRID |
| JF4  | JEFFERSON CO      | KY                   | 38.17                | 85.88                 | OUTSIDE | ROM GRID |
| JNS  | JOHNSTOWN         | PA                   | 40.31                | 78.92                 | 20.3    | 13.9     |
| JRS  | JERSEY CITY       | NJ                   | 40.73                | 74.07                 | 39.7    | 16.4     |
| KCH  | KITCHENER         | ON                   | 43.46                | 80.47                 | 14.1    | 32.7     |
| KEE  | KEENE             | NH                   | 42.92                | 72.32                 | 46.7    | 29.5     |
| KEN  | KENT CO           | MI                   | 43.04                | 85.41                 | OUTSIDE | ROM GRID |
| KNT  | KENT CO           | RI                   | 41.62                | 71.72                 | 49.1    | 21.7     |
| KUT  | KUTZTOWN          | PA                   | 40.51                | 75.79                 | 32.9    | 15.1     |
| LAN  | LANCASTER CITY    | PA                   | 40.04                | 76.29                 | 30.9    | 12.3     |
| LAW  | LAWRENCE          | MA                   | 42.71                | 71.17                 | 51.3    | 28.2     |
| LCH  | LITCHFIELD CO     | CT                   | 41.67                | 73.14                 | 43.4    | 22.0     |
| LEB  | LEBANON           | OH                   | 39.43                | 84.20                 | OUTSIDE | ROM GRID |
| LEW  | LEWISTON          | ME                   | 44.10                | 70.22                 | 55.1    | 36.6     |
| LEX  | LEXINGTON         | MA                   | 42.45                | 71.22                 | 51.1    | 26.7     |
| LF1  | LEXINGTON-FAYETTE | KY                   | 38.05                | 84.50                 | OUTSIDE | ROM GRID |
| LF2  | LEXINGTON-FAYETTE | KY                   | 38.06                | 84.50                 | OUTSIDE | ROM GRID |
| LF3  | LEXINGTON-FAYETTE | KY                   | 38.06                | 84.46                 | OUTSIDE | ROM GRID |
| LIC  | LINCOLN           | MA                   | 42.43                | 71.30                 | 50.8    | 26.6     |
| LIN  | LINDEN            | NJ                   | 40.60                | 74.25                 | 39.0    | 15.6     |
| LIV  | LIVONIA           | MI                   | 42.38                | 83.40                 | 2.4     | 26.3     |
| LND  | LONDON            | ON                   | 42.99                | 81.22                 | 11.1    | 29.9     |
| LOG  | LOGAN             | OH                   | 39.53                | 82.38                 | 6.5     | 9.2      |
| LOW  | LOWELL            | MA                   | 42.65                | 71.31                 | 50.8    | 27.9     |
| LPT  | LONG POINT PARK   | ON                   | 42.58                | 80.39                 | 14.4    | 27.5     |
| LS1  | LANSING           | MI                   | 42.74                | 84.55                 | OUTSIDE | ROM GRID |
| LS2  | LANSING           | MI                   | 42.74                | 84.54                 | OUTSIDE | ROM GRID |
| LV1  | LOUISVILLE        | KY                   | 38.25                | 85.81                 | OUTSIDE | ROM GRID |
| LV2  | LOUISVILLE        | KY                   | 38.23                | 85.70                 | OUTSIDE | ROM GRID |
| LV3  | LOUISVILLE        | KY                   | 38.26                | 85.71                 | OUTSIDE | ROM GRID |
| LV4  | LOUISVILLE        | KY                   | 38.26                | 85.76                 | OUTSIDE | ROM GRID |
| LV5  | LOUISVILLE        | KY                   | 38.23                | 85.76                 | OUTSIDE | ROM GRID |
| MAC  | MACOMB CO         | MI                   | 42.72                | 82.79                 | 4.8     | 28.3     |
| MAH  | MAHONING CO       | OH                   | 41.11                | 80.98                 | 12.1    | 18.7     |
| MAM  | MAMARONECK        | NY                   | 40.93                | 73.76                 | 40.9    | 17.6     |
| MAR  | MARION            | VA                   | 36.85                | 81.51                 | OUTSIDE | ROM GRID |
| MC1  | MC CRACKEN CO     | KY                   | 37.16                | 88.79                 | OUTSIDE | ROM GRID |
| MC2  | MC CRACKEN CO     | KY                   | 37.14                | 88.80                 | OUTSIDE | ROM GRID |
| MCG  | MC GUIRE AFB      | NJ                   | 40.05                | 74.58                 | 37.7    | 12.3     |
| MCL  | MC LEAN           | VA                   | 38.93                | 77.20                 | 27.2    | 5.6      |
| MDD  | MIDLAND           | PA                   | 40.63                | 80.44                 | 14.2    | 15.8     |
| MDL  | MIDDLETOWN        | CT                   | 41.55                | 72.63                 | 45.5    | 21.3     |
| MDN  | MEDINA CO         | OH                   | 41.15                | 81.90                 | 8.4     | 18.9     |
| MED  | MEDFIELD          | MA                   | 42.21                | 71.34                 | 50.7    | 25.3     |
| MER  | MERCER CO.        | NJ                   | 40.22                | 74.59                 | 37.6    | 13.3     |
| MFD  | MEDFORD           | MA                   | 42.40                | 71.08                 | 51.7    | 26.4     |
| MG1  | MONTGOMERY CO     | OH                   | 39.80                | 84.13                 | OUTSIDE | ROM GRID |
| MG2  | MONTGOMERY CO     | OH                   | 39.80                | 84.12                 | OUTSIDE | ROM GRID |
| MID  | MIDDLETOWN        | OH                   | 39.53                | 84.39                 | OUTSIDE | ROM GRID |

| SITE | LOCATION       | STATE OR<br>PROVINCE | LATITUDE<br>(deg, N) | LONGITUDE<br>(deg, W) | X-GRID  | Y-GRID   |
|------|----------------|----------------------|----------------------|-----------------------|---------|----------|
| MK1  | MUSKEGON       | MI                   | 43.24                | 86.20                 | OUTSIDE | ROM GRID |
| MK2  | MUSKEGON       | MI                   | 43.24                | 86.25                 | OUTSIDE | ROM GRID |
| MK3  | MUSKEGON CO    | MI                   | 43.23                | 86.22                 | OUTSIDE | ROM GRID |
| MN1  | MANCHESTER     | NH                   | 42.99                | 71.46                 | 50.1    | 30.0     |
| MN2  | MANCHESTER     | NH                   | 42.99                | 71.46                 | 50.1    | 30.0     |
| MNR  | MONROE CO      | NY                   | 43.07                | 77.71                 | 25.2    | 30.4     |
| MNT  | MONTAGUE       | MA                   | 42.57                | 72.53                 | 45.9    | 27.4     |
| MON  | MONMOUTH CO    | NJ                   | 40.33                | 74.27                 | 38.9    | 14.0     |
| MRC  | MORRIS CO      | NJ                   | 40.79                | 74.68                 | 37.3    | 16.7     |
| MRL  | MERLIN         | ON                   | 42.25                | 82.22                 | 7.1     | 25.5     |
| MRQ  | MARQUETTE CO   | MI                   | 46.81                | 87.73                 | OUTSIDE | ROM GRID |
| MRT  | MORRISTOWN     | NJ                   | 40.80                | 74.48                 | 38.1    | 16.8     |
| MSG  | MISSISSAUGA    | ON                   | 43.57                | 79.61                 | 17.6    | 33.4     |
| MU1  | MUHLenberg CO  | KY                   | 37.21                | 86.94                 | OUTSIDE | ROM GRID |
| MU2  | MUHLenberg CO  | KY                   | 37.22                | 87.05                 | OUTSIDE | ROM GRID |
| MU3  | MUHLenberg CO  | KY                   | 37.31                | 87.00                 | OUTSIDE | ROM GRID |
| N10  | NEW YORK CITY  | NY                   | 40.60                | 74.13                 | 39.5    | 15.6     |
| N11  | NEW YORK CITY  | NY                   | 40.78                | 73.91                 | 40.4    | 16.7     |
| N12  | NEW YORK CITY  | NY                   | 40.67                | 73.98                 | 40.1    | 16.0     |
| NBR  | NEW BRITAIN    | CT                   | 41.67                | 72.78                 | 44.9    | 22.0     |
| NC1  | NEW CASTLE CO  | DE                   | 39.81                | 75.45                 | 34.2    | 10.8     |
| NC2  | NEW CASTLE CO  | DE                   | 39.78                | 75.52                 | 33.9    | 10.7     |
| NC3  | NEW CASTLE CO  | DE                   | 39.70                | 75.68                 | 33.3    | 10.2     |
| NC4  | NEW CASTLE CO  | DE                   | 39.53                | 75.69                 | 33.3    | 9.2      |
| NCL  | NEW CASTLE     | PA                   | 41.00                | 80.35                 | 14.6    | 18.0     |
| NG1  | NIAGARA CO     | NY                   | 43.22                | 78.48                 | 22.1    | 31.3     |
| NG2  | NIAGARA FALLS  | NY                   | 43.09                | 79.00                 | 20.0    | 30.5     |
| NH1  | NEW HAVEN      | CT                   | 41.31                | 72.92                 | 44.3    | 19.8     |
| NH2  | NEW HAVEN      | CT                   | 41.31                | 72.92                 | 44.3    | 19.8     |
| NHP  | NORTHAMPTON CO | VA                   | 37.29                | 75.97                 | OUTSIDE | ROM GRID |
| NKS  | NEW KENSINGTON | PA                   | 40.55                | 79.76                 | 17.0    | 15.3     |
| NOR  | NORWALK        | CT                   | 41.11                | 73.41                 | 42.4    | 18.7     |
| NPN  | NEWPORT NEWS   | VA                   | 37.07                | 76.49                 | OUTSIDE | ROM GRID |
| NRF  | NORFOLK        | VA                   | 36.85                | 76.28                 | OUTSIDE | ROM GRID |
| NRS  | NORRISTOWN     | PA                   | 40.11                | 75.31                 | 34.8    | 12.7     |
| NRT  | NORTHAMPTON    | PA                   | 40.69                | 75.49                 | 34.0    | 16.1     |
| NWB  | NEW BRUNSWICK  | NJ                   | 40.48                | 74.44                 | 38.2    | 14.9     |
| NWR  | NEWARK         | NJ                   | 40.73                | 74.18                 | 39.3    | 16.4     |
| NY1  | NEW YORK CITY  | NY                   | 40.83                | 73.90                 | 40.4    | 17.0     |
| NY2  | NEW YORK CITY  | NY                   | 40.74                | 73.82                 | 40.7    | 16.4     |
| NY3  | NEW YORK CITY  | NY                   | 40.77                | 73.97                 | 40.1    | 16.6     |
| NY4  | NEW YORK CITY  | NY                   | 40.59                | 73.94                 | 40.3    | 15.6     |
| NY5  | NEW YORK CITY  | NY                   | 40.74                | 73.99                 | 40.1    | 16.4     |
| NY6  | NEW YORK CITY  | NY                   | 40.73                | 73.95                 | 40.2    | 16.4     |
| NY7  | NEW YORK CITY  | NY                   | 40.67                | 73.97                 | 40.1    | 16.0     |
| NY8  | NEW YORK CITY  | NY                   | 40.75                | 73.98                 | 40.1    | 16.5     |
| NY9  | NEW YORK CITY  | NY                   | 40.72                | 74.00                 | 40.0    | 16.3     |
| NYK  | NORTH YORK     | ON                   | 43.72                | 79.34                 | 18.6    | 34.3     |
| OCN  | OCEAN CO.      | NJ                   | 40.11                | 74.31                 | 38.8    | 12.6     |

| SITE | LOCATION     | STATE OR<br>PROVINCE | LATITUDE<br>(deg, N) | LONGITUDE<br>(deg, W) | X-GRID  | Y-GRID   |
|------|--------------|----------------------|----------------------|-----------------------|---------|----------|
| OH1  | OHIO CO      | KY                   | 37.32                | 86.93                 | OUTSIDE | ROM GRID |
| OH2  | OHIO CO      | KY                   | 37.30                | 86.95                 | OUTSIDE | ROM GRID |
| OH3  | OHIO CO      | KY                   | 37.56                | 86.77                 | OUTSIDE | ROM GRID |
| OK1  | OAKVILLE     | ON                   | 43.42                | 79.70                 | 17.2    | 32.5     |
| OK2  | OAKVILLE     | ON                   | 43.42                | 79.70                 | 17.2    | 32.5     |
| ONI  | ONEIDA CO    | NY                   | 43.30                | 75.72                 | 33.1    | 31.8     |
| ORN  | ORONO, MAINE | ME                   | 44.90                | 68.67                 | OUTSIDE | ROM GRID |
| ORO  | ORONO        | ON                   | 43.97                | 78.62                 | 21.5    | 35.8     |
| OSH  | OSHAWA       | ON                   | 43.90                | 78.85                 | 20.6    | 35.4     |
| OWN  | OWENSBORO    | KY                   | 37.78                | 87.07                 | OUTSIDE | ROM GRID |
| P10  | PHILADELPHIA | PA                   | 39.96                | 75.17                 | 35.3    | 11.7     |
| P11  | PHILADELPHIA | PA                   | 39.95                | 75.16                 | 35.3    | 11.7     |
| PAI  | PAINESVILLE  | OH                   | 41.72                | 81.24                 | 11.0    | 22.3     |
| PAT  | PATERSON     | NJ                   | 40.93                | 74.16                 | 39.4    | 17.6     |
| PAU  | PAULSBORO    | NJ                   | 39.83                | 75.24                 | 35.0    | 11.0     |
| PB1  | PENOBSCOT CO | ME                   | 45.01                | 68.63                 | OUTSIDE | ROM GRID |
| PB2  | PENOBSCOT CO | ME                   | 44.73                | 68.98                 | OUTSIDE | ROM GRID |
| PB3  | PENOBSCOT CO | ME                   | 45.25                | 68.57                 | OUTSIDE | ROM GRID |
| PD1  | PADUCAH      | KY                   | 37.08                | 88.60                 | OUTSIDE | ROM GRID |
| PD2  | PADUCAH      | KY                   | 37.09                | 88.60                 | OUTSIDE | ROM GRID |
| PD3  | PADUCAH      | KY                   | 37.06                | 88.57                 | OUTSIDE | ROM GRID |
| PEN  | PENNS GROVE  | NJ                   | 39.73                | 75.47                 | 34.1    | 10.4     |
| PH1  | PHILADELPHIA | PA                   | 40.01                | 75.10                 | 35.6    | 12.1     |
| PH2  | PHILADELPHIA | PA                   | 40.05                | 75.24                 | 35.0    | 12.3     |
| PH3  | PHILADELPHIA | PA                   | 39.98                | 75.10                 | 35.6    | 11.9     |
| PH4  | PHILADELPHIA | PA                   | 39.88                | 75.23                 | 35.1    | 11.3     |
| PH5  | PHILADELPHIA | PA                   | 39.92                | 75.19                 | 35.2    | 11.5     |
| PH6  | PHILADELPHIA | PA                   | 39.91                | 75.15                 | 35.4    | 11.4     |
| PH7  | PHILADELPHIA | PA                   | 40.08                | 75.01                 | 36.0    | 12.5     |
| PH8  | PHILADELPHIA | PA                   | 39.95                | 75.16                 | 35.3    | 11.7     |
| PH9  | PHILADELPHIA | PA                   | 40.01                | 75.15                 | 35.4    | 12.1     |
| PLN  | PLAINFIELD   | NJ                   | 40.60                | 74.44                 | 38.2    | 15.6     |
| PLS  | PULASKI CO   | KY                   | 37.16                | 84.48                 | OUTSIDE | ROM GRID |
| PLY  | PLYMOUTH     | NH                   | 43.78                | 71.75                 | 49.0    | 34.7     |
| P01  | PORTSMOUTH   | NH                   | 43.08                | 70.76                 | 52.9    | 30.5     |
| P02  | PORTSMOUTH   | NH                   | 43.08                | 70.76                 | 53.0    | 30.5     |
| POR  | PORTLAND     | ME                   | 43.66                | 70.26                 | 55.0    | 34.0     |
| POU  | POUGHKEEPSIE | NY                   | 41.70                | 73.94                 | 40.3    | 22.2     |
| PRB  | PREBLE CO    | OH                   | 39.84                | 84.72                 | OUTSIDE | ROM GRID |
| PRH  | PORT HURON   | MI                   | 42.95                | 82.44                 | 6.2     | 29.7     |
| PRY  | PERRY CO     | PA                   | 40.46                | 77.17                 | 27.3    | 14.7     |
| PSB  | PHILLIPSBURG | NJ                   | 40.68                | 75.19                 | 35.3    | 16.1     |
| PSQ  | PRESQUE ISLE | ME                   | 46.69                | 68.00                 | OUTSIDE | ROM GRID |
| PT1  | PITTSBURGH   | PA                   | 40.44                | 80.00                 | 16.0    | 14.6     |
| PT2  | PITTSBURGH   | PA                   | 40.47                | 79.96                 | 16.2    | 14.8     |
| PT3  | PITTSBURGH   | PA                   | 40.44                | 79.95                 | 16.2    | 14.6     |
| PTG  | PORTAGE CO   | OH                   | 41.18                | 81.33                 | 10.7    | 19.1     |
| PTH  | PERTH AMBOY  | NJ                   | 40.51                | 74.27                 | 38.9    | 15.1     |
| PTR  | PETROLIA     | ON                   | 42.96                | 82.19                 | 7.2     | 29.7     |

| SITE | LOCATION             | STATE OR<br>PROVINCE | LATITUDE<br>(deg, N) | LONGITUDE<br>(deg, W) | X-GRID  | Y-GRID   |
|------|----------------------|----------------------|----------------------|-----------------------|---------|----------|
| PTS  | PITTSFIELD           | MA                   | 42.45                | 73.20                 | 43.2    | 26.7     |
| PV1  | PROVIDENCE           | RI                   | 41.82                | 71.41                 | 50.4    | 22.9     |
| PV2  | PROVIDENCE           | RI                   | 41.82                | 71.41                 | 50.4    | 22.9     |
| PV3  | PROVIDENCE           | RI                   | 41.83                | 71.41                 | 50.3    | 23.0     |
| PV4  | PROVIDENCE           | RI                   | 41.83                | 71.41                 | 50.4    | 23.0     |
| PWM  | PRINCE WILLIAM CO    | VA                   | 38.64                | 77.53                 | 25.9    | 3.9      |
| QIN  | QUINCY               | MA                   | 42.24                | 70.97                 | 52.1    | 25.5     |
| RC1  | ROCHESTER            | NY                   | 43.16                | 77.60                 | 25.6    | 31.0     |
| RC2  | ROCHESTER            | NY                   | 43.17                | 77.52                 | 25.9    | 31.0     |
| RCK  | ROCKVILLE            | MD                   | 39.11                | 77.11                 | 27.6    | 6.7      |
| RDG  | READING              | PA                   | 40.32                | 75.93                 | 32.3    | 13.9     |
| REN  | RENSSELAER           | NY                   | 42.63                | 73.75                 | 41.0    | 27.8     |
| RIC  | RICHMOND             | VA                   | 37.54                | 77.43                 | OUTSIDE | ROM GRID |
| RIM  | RICHMOND             | VA                   | 37.49                | 77.47                 | OUTSIDE | ROM GRID |
| RVB  | RIVIERA BEACH        | MD                   | 39.16                | 76.51                 | 30.0    | 7.0      |
| SAG  | SAGINAW              | MI                   | 43.45                | 83.91                 | 0.4     | 32.7     |
| SAL  | SALINE               | MI                   | 42.16                | 83.78                 | 0.9     | 24.9     |
| SC1  | SCRANTON             | PA                   | 41.44                | 75.62                 | 33.5    | 20.7     |
| SC2  | SCRANTON             | PA                   | 41.59                | 76.07                 | 31.7    | 21.6     |
| SCH  | SCHENECTADY          | NY                   | 42.80                | 73.94                 | 40.2    | 28.8     |
| SCR  | SCARBOROUGH          | ON                   | 43.75                | 79.27                 | 18.9    | 34.5     |
| SDB  | SUDBURY              | MA                   | 42.38                | 71.39                 | 50.4    | 26.3     |
| SHP  | SHEPHERDSVILLE       | KY                   | 38.00                | 85.70                 | OUTSIDE | ROM GRID |
| SLM  | SALEM                | VA                   | 37.29                | 80.05                 | OUTSIDE | ROM GRID |
| SMC  | SIMCOE               | ON                   | 42.86                | 80.27                 | 14.9    | 29.1     |
| SMT  | ST MATTHEWS          | KY                   | 38.25                | 85.81                 | OUTSIDE | ROM GRID |
| SMV  | SOMERVILLE           | NJ                   | 40.57                | 74.61                 | 37.5    | 15.4     |
| SOM  | SOMERVILLE           | MA                   | 42.40                | 71.11                 | 51.6    | 26.4     |
| SP1  | SPRINGFIELD          | MA                   | 42.09                | 72.59                 | 45.6    | 24.5     |
| SP2  | SPRINGFIELD          | MA                   | 42.14                | 72.49                 | 46.0    | 24.8     |
| SR2  | SARNIA               | ON                   | 42.98                | 82.41                 | 6.4     | 29.9     |
| STC  | ST. CATHERINES       | ON                   | 43.17                | 79.24                 | 19.0    | 31.0     |
| STF  | STAFFORD             | CT                   | 41.98                | 72.39                 | 46.5    | 23.9     |
| STH  | SOUTHFIELD           | MI                   | 42.45                | 83.22                 | 3.1     | 26.7     |
| STK  | STARK CO             | OH                   | 40.87                | 81.33                 | 10.7    | 17.2     |
| STM  | STAMFORD             | CT                   | 41.06                | 73.54                 | 41.8    | 18.3     |
| STR  | STRATFORD            | CT                   | 41.15                | 73.15                 | 43.4    | 18.9     |
| STU  | STEUBENVILLE         | OH                   | 40.36                | 80.62                 | 13.5    | 14.2     |
| STV  | STOUFFVILLE          | ON                   | 43.97                | 79.27                 | 18.9    | 35.8     |
| SUS  | SUSSEX CO            | DE                   | 38.58                | 75.27                 | 34.9    | 3.5      |
| SUT  | SUITLAND-SILVER HILL | MD                   | 38.85                | 76.93                 | 28.3    | 5.1      |
| SVC  | SEVEN CORNERS        | VA                   | 38.87                | 77.14                 | 27.4    | 5.2      |
| SY1  | SYRACUSE             | NY                   | 43.05                | 76.15                 | 31.4    | 30.3     |
| SY2  | SYRACUSE             | NY                   | 43.06                | 76.18                 | 31.3    | 30.4     |
| SY3  | SYRACUSE             | NY                   | 43.06                | 76.13                 | 31.5    | 30.4     |
| SY4  | SYRACUSE             | NY                   | 43.06                | 76.18                 | 31.3    | 30.4     |
| SYB  | STONY BROOK          | NY                   | 40.91                | 73.13                 | 43.5    | 17.5     |
| TEW  | TEWKSBURY            | MA                   | 42.61                | 71.22                 | 51.1    | 27.6     |
| TL1  | TOLEDO               | OH                   | 41.65                | 83.53                 | 1.9     | 21.9     |

| SITE | LOCATION       | STATE OR<br>PROVINCE | LATITUDE<br>(deg, N) | LONGITUDE<br>(deg, W) | X-GRID  | Y-GRID   |
|------|----------------|----------------------|----------------------|-----------------------|---------|----------|
| TL2  | TOLEDO         | OH                   | 41.66                | 83.53                 | 1.9     | 21.9     |
| TL3  | TOLEDO         | OH                   | 41.66                | 83.57                 | 1.7     | 22.0     |
| TL4  | TOLEDO         | OH                   | 41.72                | 83.48                 | 2.1     | 22.3     |
| TOM  | TOMS RIVER     | NJ                   | 39.95                | 74.20                 | 39.2    | 11.7     |
| TR1  | TORONTO        | ON                   | 43.66                | 79.39                 | 18.4    | 34.0     |
| TR2  | TORONTO        | ON                   | 43.65                | 79.37                 | 18.5    | 33.9     |
| TRE  | TRENTON        | MI                   | 42.14                | 83.19                 | 3.3     | 24.8     |
| TRM  | TRIMBLE CO     | KY                   | 38.71                | 85.42                 | OUTSIDE | ROM GRID |
| TRN  | TRENTON        | NJ                   | 40.22                | 74.76                 | 36.9    | 13.3     |
| TV2  | TIVERTON       | ON                   | 44.30                | 81.58                 | 9.7     | 37.8     |
| UTC  | UTICA          | NY                   | 43.10                | 75.20                 | 35.2    | 30.6     |
| VAB  | VIRGINIA BEACH | VA                   | 36.89                | 76.18                 | OUTSIDE | ROM GRID |
| VIN  | VINELAND       | NJ                   | 39.49                | 75.02                 | 35.9    | 9.0      |
| WAT  | WATERTOWN      | MA                   | 42.37                | 71.18                 | 51.3    | 26.2     |
| WAY  | WAYNE CO       | NY                   | 43.23                | 77.17                 | 27.3    | 31.4     |
| WCH  | WINCHESTER     | KY                   | 38.00                | 84.17                 | OUTSIDE | ROM GRID |
| WH1  | WHEELING       | WV                   | 40.07                | 80.72                 | 13.1    | 12.4     |
| WH2  | WHEELING       | WV                   | 40.12                | 80.70                 | 13.2    | 12.7     |
| WIL  | WILMINGTON     | DE                   | 39.73                | 75.55                 | 33.8    | 10.4     |
| WL1  | WILLIAMSPORT   | PA                   | 41.25                | 76.99                 | 28.0    | 19.5     |
| WL2  | WILLIAMSPORT   | PA                   | 41.25                | 76.99                 | 28.0    | 19.5     |
| WLK  | WILKES-BARRE   | PA                   | 41.24                | 75.90                 | 32.4    | 19.4     |
| WLO  | WILLOUGHBY     | OH                   | 41.64                | 81.41                 | 10.4    | 21.8     |
| WNS  | WINDSOR        | ON                   | 42.32                | 83.04                 | 3.8     | 25.9     |
| WO1  | WORCESTER      | MA                   | 42.26                | 71.80                 | 48.8    | 25.6     |
| WO2  | WORCESTER      | MA                   | 42.30                | 71.75                 | 49.0    | 25.8     |
| WPL  | WHITE PLAINS   | NY                   | 41.05                | 73.76                 | 40.9    | 18.3     |
| WRN  | WARREN         | MI                   | 42.51                | 83.01                 | 4.0     | 27.1     |
| WSL  | WESTLAKE       | OH                   | 41.48                | 81.88                 | 8.5     | 20.9     |
| YG1  | YOUNGSTOWN     | OH                   | 41.10                | 80.65                 | 13.4    | 18.6     |
| YG2  | YOUNGSTOWN     | OH                   | 41.10                | 80.65                 | 13.4    | 18.6     |
| YOR  | YORK           | PA                   | 39.97                | 76.70                 | 29.2    | 11.8     |

## APPENDIX B

### MAXIMUM O<sub>3</sub> VALUES AT SURFACE MONITORING STATIONS

This appendix contains a list of the surface monitoring sites operating during the 3-4 August 1979 period along with the observed and predicted maximum O<sub>3</sub> values at these sites for each of the days and the hour that the maximum value occurred. All concentrations are in units of ppb and times are in hours, LST.

| DATE  | SITE | $c_{ob}^{max}$ | $h_{ob}^{max}$ | $c_{p0}(h_{ob}^{max})$ | $c_{p1}(h_{ob}^{max})$ | $c_{p0}^{max}$ | $h_{p0}^{max}$ | $c_{p1}^{max}$ | $h_{p1}^{max}$ |
|-------|------|----------------|----------------|------------------------|------------------------|----------------|----------------|----------------|----------------|
| 79215 | AA1  | 69.0           | 14             | 36.4                   | 38.5                   | 42.8           | 17             | 46.0           | 18             |
| 79215 | AA2  | 71.0           | 14             | 36.4                   | 38.5                   | 42.8           | 17             | 45.9           | 16             |
| 79215 | AC1  | 76.0           | 12             | 31.6                   | 32.1                   | 37.0           | 9              | 37.5           | 9              |
| 79215 | AG4  | 57.0           | 15             | 33.9                   | 33.9                   | 35.1           | 13             | 35.1           | 13             |
| 79215 | AGA  | 100.0          | 16             | 16.0                   | 16.2                   | 37.7           | 13             | 38.3           | 13             |
| 79215 | AK1  | 58.0           | 18             | 37.6                   | 38.0                   | 40.0           | 16             | 40.4           | 16             |
| 79215 | ALN  | 59.0           | 17             | 20.8                   | 22.3                   | 33.1           | 9              | 35.1           | 8              |
| 79215 | ALX  | 75.0           | 14             | 69.5                   | 72.0                   | 70.0           | 15             | 72.3           | 15             |
| 79215 | AMH  | 69.0           | 18             | 39.8                   | 41.4                   | 40.4           | 17             | 41.5           | 17             |
| 79215 | AMR  | 99.0           | 14             | 33.6                   | 33.9                   | 37.5           | 17             | 37.9           | 17             |
| 79215 | ARL  | 100.0          | 14             | 69.5                   | 72.0                   | 70.0           | 15             | 72.3           | 15             |
| 79215 | ATL  | 87.0           | 11             | 42.1                   | 43.7                   | 42.1           | 11             | 43.7           | 11             |
| 79215 | BAB  | 83.0           | 11             | 10.2                   | 10.6                   | 24.6           | 20             | 25.1           | 20             |
| 79215 | BAD  | 31.0           | 14             | 23.1                   | 23.5                   | 26.4           | 17             | 26.9           | 17             |
| 79215 | BAY  | 91.0           | 12             | 47.1                   | 47.8                   | 59.4           | 16             | 59.8           | 16             |
| 79215 | BER  | 53.0           | 9              | 32.3                   | 34.5                   | 47.5           | 17             | 49.8           | 17             |
| 79215 | BET  | 55.0           | 17             | 18.4                   | 19.5                   | 30.2           | 9              | 31.4           | 9              |
| 79215 | BL1  | 37.0           | 14             | 26.0                   | 26.3                   | 28.2           | 10             | 28.3           | 10             |
| 79215 | BL3  | 38.0           | 14             | 26.0                   | 26.3                   | 31.0           | 8              | 31.2           | 8              |
| 79215 | BL6  | 70.0           | 14             | 31.8                   | 33.0                   | 36.3           | 17             | 38.8           | 18             |
| 79215 | BLG  | 55.0           | 13             | 40.3                   | 40.5                   | 48.0           | 22             | 48.8           | 22             |
| 79215 | BN1  | 41.0           | 16             | 40.7                   | 41.6                   | 41.3           | 18             | 41.9           | 17             |
| 79215 | BNG  | 79.0           | 14             | 37.8                   | 38.0                   | 38.5           | 15             | 38.4           | 15             |
| 79215 | BNW  | 66.0           | 16             | 45.6                   | 48.3                   | 55.6           | 20             | 57.3           | 20             |
| 79215 | BR2  | 117.0          | 14             | 42.6                   | 43.0                   | 92.2           | 18             | 93.0           | 18             |
| 79215 | BRI  | 100.0          | 14             | 46.4                   | 49.1                   | 62.8           | 17             | 67.8           | 17             |
| 79215 | BTH  | 61.0           | 14             | 52.5                   | 55.0                   | 56.2           | 13             | 58.9           | 13             |
| 79215 | BUL  | 87.0           | 12             | 36.9                   | 39.5                   | 51.2           | 15             | 53.5           | 15             |
| 79215 | BVF  | 29.0           | 18             | 26.6                   | 27.2                   | 26.6           | 18             | 27.2           | 18             |
| 79215 | CAN  | 55.0           | 16             | 38.2                   | 38.4                   | 38.2           | 16             | 38.4           | 16             |
| 79215 | CB1  | 85.0           | 19             | 32.2                   | 33.2                   | 34.2           | 14             | 34.8           | 14             |
| 79215 | CB4  | 66.0           | 19             | 32.2                   | 33.2                   | 34.2           | 14             | 34.8           | 14             |
| 79215 | CHL  | 79.0           | 16             | 24.8                   | 25.0                   | 31.1           | 8              | 32.0           | 8              |
| 79215 | CHR  | 100.0          | 17             | 51.3                   | 52.0                   | 51.3           | 17             | 52.0           | 17             |
| 79215 | CHS  | 60.2           | 12             | 29.2                   | 33.8                   | 31.9           | 13             | 35.3           | 9              |
| 79215 | CHT  | 83.0           | 13             | 50.1                   | 54.3                   | 51.9           | 14             | 55.9           | 14             |
| 79215 | CHV  | 64.0           | 14             | 52.5                   | 55.0                   | 56.2           | 13             | 58.9           | 13             |
| 79215 | CKY  | 66.0           | 15             | 33.5                   | 36.4                   | 33.5           | 15             | 36.4           | 15             |
| 79215 | CL2  | 63.0           | 12             | 39.1                   | 39.9                   | 51.7           | 18             | 52.8           | 18             |
| 79215 | CLK  | 105.0          | 15             | 33.2                   | 36.0                   | 34.2           | 20             | 36.2           | 9              |
| 79215 | CM1  | 89.0           | 13             | 41.3                   | 45.1                   | 59.2           | 15             | 64.5           | 16             |
| 79215 | CM3  | 84.0           | 14             | 32.0                   | 33.7                   | 41.2           | 12             | 43.4           | 12             |
| 79215 | CNE  | 159.0          | 16             | 41.5                   | 41.4                   | 47.7           | 19             | 47.7           | 19             |
| 79215 | CPE  | 105.0          | 18             | 38.1                   | 38.5                   | 42.2           | 23             | 42.8           | 23             |
| 79215 | DAN  | 120.0          | 16             | 38.7                   | 38.8                   | 49.5           | 17             | 49.7           | 17             |
| 79215 | DC1  | 15.0           | 10             | 39.9                   | 41.1                   | 39.9           | 10             | 41.1           | 10             |
| 79215 | DC4  | 10.0           | 15             | 70.0                   | 72.3                   | 70.0           | 15             | 72.3           | 15             |
| 79215 | DC5  | 125.0          | 16             | 41.4                   | 43.9                   | 56.2           | 13             | 58.9           | 13             |
| 79215 | DC6  | 100.0          | 17             | 40.2                   | 42.0                   | 56.2           | 13             | 58.9           | 13             |
| 79215 | DNR  | 95.0           | 16             | 26.7                   | 27.3                   | 33.1           | 7              | 34.5           | 7              |

| DATE  | SITE | $c_{ob}^{max}$ | $h_{ob}^{max}$ | $c_{p0}(h_{ob}^{max})$ | $c_{p1}(h_{ob}^{max})$ | $c_{p0}^{max}$ | $h_{p0}^{max}$ | $c_{p1}^{max}$ | $h_{p1}^{max}$ |
|-------|------|----------------|----------------|------------------------|------------------------|----------------|----------------|----------------|----------------|
| 79215 | DOW  | 96.0           | 14             | 31.9                   | 37.1                   | 33.2           | 15             | 37.5           | 15             |
| 79215 | DRB  | 104.0          | 15             | 33.7                   | 34.1                   | 85.0           | 19             | 86.0           | 19             |
| 79215 | DT3  | 43.9           | 15             | 44.5                   | 44.9                   | 72.7           | 10             | 73.4           | 10             |
| 79215 | DT4  | 25.0           | 15             | 30.1                   | 30.2                   | 70.2           | 9              | 71.1           | 9              |
| 79215 | EB1  | 75.0           | 15             | 46.0                   | 46.9                   | 59.0           | 10             | 61.0           | 10             |
| 79215 | EB2  | 62.0           | 15             | 46.0                   | 46.9                   | 59.0           | 10             | 61.0           | 10             |
| 79215 | ERE  | 95.0           | 14             | 39.6                   | 39.7                   | 40.0           | 15             | 40.1           | 16             |
| 79215 | ESS  | 63.3           | 17             | 36.5                   | 36.5                   | 37.2           | 7              | 37.2           | 8              |
| 79215 | ESX  | 80.0           | 15             | 25.3                   | 25.4                   | 31.0           | 6              | 31.6           | 7              |
| 79215 | EXC  | 67.0           | 23             | 36.1                   | 38.5                   | 38.8           | 18             | 39.3           | 17             |
| 79215 | EY1  | 75.0           | 17             | 40.2                   | 42.3                   | 42.8           | 16             | 45.4           | 15             |
| 79215 | FDR  | 100.0          | 13             | 35.3                   | 37.0                   | 38.5           | 15             | 40.9           | 16             |
| 79215 | FLN  | 57.7           | 12             | 35.7                   | 37.3                   | 35.7           | 11             | 37.4           | 11             |
| 79215 | FX1  | 92.3           | 14             | 52.4                   | 52.9                   | 54.3           | 13             | 54.8           | 13             |
| 79215 | FX2  | 115.0          | 14             | 68.2                   | 71.7                   | 81.7           | 17             | 87.1           | 16             |
| 79215 | GAR  | 78.0           | 14             | 41.7                   | 42.7                   | 42.6           | 17             | 43.3           | 17             |
| 79215 | GLN  | 65.0           | 15             | 43.8                   | 45.3                   | 43.8           | 15             | 45.3           | 15             |
| 79215 | GLO  | 102.0          | 14             | 38.9                   | 40.1                   | 50.0           | 17             | 50.9           | 17             |
| 79215 | GMT  | 45.0           | 10             | 35.0                   | 37.5                   | 39.2           | 18             | 40.5           | 17             |
| 79215 | GRE  | 38.0           | 18             | 22.5                   | 22.6                   | 36.4           | 6              | 36.8           | 6              |
| 79215 | GRG  | 69.0           | 12             | 39.1                   | 40.4                   | 52.6           | 16             | 53.4           | 16             |
| 79215 | GRW  | 130.0          | 14             | 88.5                   | 89.7                   | 95.0           | 15             | 96.7           | 15             |
| 79215 | HAR  | 69.0           | 17             | 41.8                   | 43.6                   | 44.5           | 18             | 44.6           | 18             |
| 79215 | HF2  | 100.0          | 14             | 27.2                   | 27.5                   | 38.0           | 11             | 38.6           | 11             |
| 79215 | HGR  | 46.0           | 13             | 31.0                   | 35.3                   | 32.6           | 9              | 36.2           | 16             |
| 79215 | HM1  | 54.0           | 11             | 10.2                   | 10.6                   | 24.6           | 20             | 25.1           | 20             |
| 79215 | HML  | 68.0           | 17             | 47.2                   | 47.9                   | 48.0           | 22             | 48.8           | 22             |
| 79215 | HRP  | 63.0           | 12             | 34.6                   | 37.6                   | 34.6           | 12             | 37.6           | 12             |
| 79215 | JNS  | 65.0           | 16             | 26.3                   | 27.6                   | 30.1           | 9              | 33.6           | 9              |
| 79215 | KCH  | 76.0           | 17             | 31.4                   | 33.9                   | 64.9           | 21             | 68.2           | 21             |
| 79215 | KNT  | 115.0          | 13             | 35.9                   | 36.2                   | 40.7           | 17             | 41.0           | 17             |
| 79215 | LAN  | 56.0           | 16             | 33.5                   | 40.7                   | 43.1           | 20             | 45.9           | 20             |
| 79215 | LEX  | 70.0           | 14             | 47.4                   | 49.1                   | 54.6           | 15             | 55.3           | 15             |
| 79215 | LIC  | 76.0           | 16             | 47.5                   | 48.4                   | 54.6           | 15             | 55.3           | 15             |
| 79215 | LIV  | 39.8           | 12             | 38.0                   | 38.5                   | 39.3           | 16             | 39.9           | 16             |
| 79215 | LND  | 64.0           | 13             | 66.6                   | 72.8                   | 119.0          | 21             | 122.0          | 21             |
| 79215 | MAM  | 54.0           | 15             | 95.0                   | 96.7                   | 95.0           | 15             | 96.7           | 15             |
| 79215 | MCL  | 50.0           | 13             | 38.3                   | 40.9                   | 38.3           | 13             | 41.3           | 12             |
| 79215 | MED  | 50.0           | 9              | 39.8                   | 40.9                   | 39.8           | 9              | 40.9           | 9              |
| 79215 | MER  | 102.0          | 12             | 31.7                   | 35.3                   | 40.1           | 15             | 44.0           | 16             |
| 79215 | MFD  | 66.0           | 14             | 53.9                   | 56.0                   | 53.9           | 14             | 56.0           | 14             |
| 79215 | MN1  | 75.0           | 17             | 33.2                   | 34.1                   | 37.3           | 15             | 37.7           | 15             |
| 79215 | MNR  | 61.0           | 17             | 33.2                   | 35.4                   | 34.4           | 12             | 36.3           | 11             |
| 79215 | MRC  | 69.0           | 14             | 33.7                   | 37.7                   | 33.8           | 13             | 37.7           | 13             |
| 79215 | MSG  | 70.0           | 15             | 48.9                   | 48.6                   | 56.8           | 10             | 56.4           | 10             |
| 79215 | N10  | 123.0          | 12             | 44.7                   | 45.7                   | 65.7           | 15             | 67.3           | 15             |
| 79215 | NC1  |                |                | MISSING DATA           |                        |                |                |                |                |
| 79215 | NC4  | 92.0           | 12             | 35.1                   | 36.6                   | 45.9           | 20             | 48.6           | 20             |
| 79215 | NCL  | 31.0           | 18             | 35.6                   | 37.9                   | 37.0           | 17             | 39.2           | 17             |

| DATE  | SITE | $c_{ob}^{max}$ | $h_{ob}^{max}$ | $c_{p0}(h_{ob}^{max})$ | $c_{p1}(h_{ob}^{max})$ | $c_{p0}^{max}$ | $h_{p0}^{max}$ | $c_{p1}^{max}$ | $h_{p1}^{max}$ |
|-------|------|----------------|----------------|------------------------|------------------------|----------------|----------------|----------------|----------------|
| 79215 | NG2  | 72.0           | 17             | 40.0                   | 40.1                   | 40.0           | 17             | 40.3           | 18             |
| 79215 | NH2  | 30.0           | 8              | 29.9                   | 30.7                   | 31.4           | 7              | 32.1           | 7              |
| 79215 | NRS  | 110.0          | 14             | 37.4                   | 41.8                   | 46.6           | 18             | 52.9           | 18             |
| 79215 | NY2  | 87.0           | 13             | 31.3                   | 31.9                   | 39.5           | 18             | 40.0           | 18             |
| 79215 | NY4  | 101.0          | 12             | 47.1                   | 47.8                   | 59.4           | 16             | 59.8           | 16             |
| 79215 | NY5  | 83.0           | 13             | 53.2                   | 53.9                   | 59.4           | 16             | 59.8           | 16             |
| 79215 | NYK  | 48.0           | 13             | 53.8                   | 53.6                   | 72.2           | 11             | 72.4           | 11             |
| 79215 | OCN  | 95.0           | 11             | 38.0                   | 42.7                   | 42.5           | 15             | 45.3           | 15             |
| 79215 | OK1  | 64.0           | 13             | 41.1                   | 42.7                   | 42.0           | 16             | 43.8           | 16             |
| 79215 | ORO  | 98.0           | 16             | 92.5                   | 99.3                   | 104.0          | 14             | 110.0          | 14             |
| 79215 | OSH  | 55.0           | 16             | 58.0                   | 57.6                   | 93.7           | 12             | 93.6           | 12             |
| 79215 | P10  | 80.0           | 16             | 48.7                   | 55.3                   | 54.4           | 15             | 55.5           | 15             |
| 79215 | PAI  | 54.0           | 13             | 41.2                   | 41.3                   | 47.7           | 19             | 48.2           | 19             |
| 79215 | PH1  | 80.0           | 12             | 35.3                   | 38.0                   | 59.2           | 15             | 64.5           | 16             |
| 79215 | PH2  | 90.0           | 12             | 35.1                   | 35.9                   | 54.4           | 15             | 55.5           | 15             |
| 79215 | PH4  | 60.0           | 15             | 46.0                   | 48.3                   | 51.9           | 14             | 55.9           | 14             |
| 79215 | PH5  | 60.0           | 12             | 35.1                   | 35.9                   | 54.4           | 15             | 55.5           | 15             |
| 79215 | PH6  | 40.0           | 12             | 46.0                   | 49.1                   | 51.9           | 14             | 55.9           | 14             |
| 79215 | PH7  | 110.0          | 12             | 35.3                   | 38.0                   | 59.2           | 15             | 64.5           | 16             |
| 79215 | PH8  |                |                | MISSING DATA           |                        |                |                |                |                |
| 79215 | PLY  | 50.0           | 13             | 39.3                   | 39.9                   | 39.3           | 13             | 39.9           | 13             |
| 79215 | POU  | 41.0           | 17             | 3.8                    | 4.0                    | 32.6           | 9              | 33.6           | 9              |
| 79215 | PRH  | 65.3           | 13             | 66.6                   | 67.2                   | 89.1           | 16             | 89.9           | 16             |
| 79215 | PT2  | 76.0           | 15             | 29.4                   | 29.4                   | 29.5           | 16             | 29.6           | 16             |
| 79215 | PTG  | 77.0           | 14             | 32.2                   | 33.3                   | 38.8           | 17             | 40.2           | 17             |
| 79215 | PTR  | 87.0           | 16             | 116.0                  | 120.0                  | 116.0          | 16             | 120.0          | 16             |
| 79215 | PTS  | 62.0           | 14             | 10.3                   | 10.4                   | 23.1           | 7              | 23.5           | 7              |
| 79215 | PV3  | 75.0           | 13             | 36.7                   | 38.6                   | 40.7           | 19             | 41.9           | 19             |
| 79215 | RDG  | 36.0           | 14             | 33.5                   | 36.7                   | 36.7           | 17             | 40.2           | 17             |
| 79215 | REN  | 78.0           | 15             | 10.9                   | 11.4                   | 26.1           | 7              | 26.4           | 7              |
| 79215 | RVB  | 73.0           | 13             | 31.7                   | 32.7                   | 34.0           | 12             | 35.6           | 12             |
| 79215 | SC1  | 113.0          | 13             | 37.2                   | 39.5                   | 41.3           | 16             | 42.4           | 16             |
| 79215 | SCH  | 71.0           | 14             | 38.4                   | 38.8                   | 38.4           | 14             | 38.9           | 13             |
| 79215 | SCR  | 66.0           | 15             | 51.0                   | 50.9                   | 72.2           | 11             | 72.4           | 11             |
| 79215 | SMC  | 84.0           | 14             | 39.7                   | 41.4                   | 46.4           | 23             | 48.0           | 23             |
| 79215 | SMV  | 51.0           | 13             | 41.2                   | 43.2                   | 46.8           | 23             | 49.1           | 23             |
| 79215 | SR2  | 100.0          | 12             | 57.1                   | 57.4                   | 89.1           | 16             | 89.9           | 16             |
| 79215 | STC  | 72.0           | 17             | 39.4                   | 40.4                   | 40.9           | 23             | 41.7           | 23             |
| 79215 | STH  | 26.5           | 12             | 42.8                   | 43.9                   | 45.2           | 10             | 46.5           | 10             |
| 79215 | STU  | 100.0          | 17             | 22.4                   | 23.1                   | 29.4           | 13             | 30.4           | 13             |
| 79215 | STV  | 81.0           | 15             | 58.9                   | 66.0                   | 68.6           | 13             | 77.0           | 13             |
| 79215 | SVC  | 97.4           | 14             | 52.4                   | 52.9                   | 54.3           | 13             | 54.8           | 13             |
| 79215 | SY1  | 72.0           | 15             | 23.6                   | 24.1                   | 36.8           | 10             | 38.0           | 10             |
| 79215 | SY2  | 78.0           | 15             | 23.6                   | 24.1                   | 36.8           | 10             | 38.0           | 10             |
| 79215 | SY4  | 78.0           | 15             | 23.6                   | 24.1                   | 36.8           | 10             | 38.0           | 10             |
| 79215 | TL1  | 70.0           | 19             | 34.9                   | 35.9                   | 42.5           | 11             | 43.5           | 11             |
| 79215 | TL4  | 65.0           | 14             | 37.3                   | 38.1                   | 40.3           | 12             | 41.1           | 12             |
| 79215 | TR1  | 64.0           | 17             | 40.6                   | 41.7                   | 59.0           | 10             | 61.0           | 10             |
| 79215 | TR2  | 41.0           | 11             | 72.2                   | 72.4                   | 72.2           | 11             | 72.4           | 11             |

| DATE  | SITE | $c_{ob}^{max}$ | $h_{ob}^{max}$ | $c_{p0}(h_{ob}^{max})$ | $c_{p1}(h_{ob}^{max})$ | $c_{p0}^{max}$ | $h_{p0}^{max}$ | $c_{p1}^{max}$ | $h_{p1}^{max}$ |
|-------|------|----------------|----------------|------------------------|------------------------|----------------|----------------|----------------|----------------|
| 79215 | TRN  | 81.0           | 13             | 36.9                   | 37.3                   | 55.9           | 17             | 58.4           | 17             |
| 79215 | UTC  | 83.0           | 17             | 37.5                   | 38.7                   | 38.2           | 18             | 39.2           | 18             |
| 79215 | VIN  | 77.0           | 13             | 29.4                   | 33.6                   | 35.6           | 20             | 38.1           | 20             |
| 79215 | WH2  | 69.9           | 18             | 23.2                   | 25.1                   | 30.4           | 10             | 32.9           | 8              |
| 79215 | WLK  | 72.0           | 13             | 29.8                   | 31.9                   | 33.0           | 9              | 35.2           | 6              |
| 79215 | WNS  | 92.0           | 10             | 65.9                   | 66.6                   | 65.9           | 10             | 66.6           | 10             |
| 79215 | WO1  | 52.0           | 15             | 53.7                   | 54.4                   | 57.0           | 17             | 57.8           | 17             |
| 79215 | WO2  | 65.0           | 18             | 55.1                   | 55.8                   | 57.0           | 17             | 57.8           | 17             |
| 79215 | WRN  | 62.2           | 13             | 53.4                   | 53.8                   | 57.2           | 12             | 57.8           | 12             |
| 79215 | YG2  | 70.0           | 16             | 36.1                   | 36.9                   | 37.2           | 17             | 38.0           | 17             |
| 79216 | AA1  | 94.0           | 13             | 35.6                   | 37.1                   | 36.7           | 12             | 38.3           | 12             |
| 79216 | AA2  | 88.0           | 12             | 36.7                   | 38.3                   | 36.7           | 12             | 38.3           | 12             |
| 79216 | AC1  | 73.0           | 11             | 85.8                   | 87.1                   | 127.0          | 14             | 130.0          | 15             |
| 79216 | AG4  | 78.0           | 13             | 36.8                   | 36.8                   | 39.4           | 18             | 39.6           | 18             |
| 79216 | AGA  | 90.0           | 13             | 36.6                   | 37.6                   | 42.5           | 15             | 43.5           | 15             |
| 79216 | AK1  | 80.0           | 13             | 32.8                   | 33.0                   | 46.9           | 19             | 47.5           | 19             |
| 79216 | ALN  | 75.0           | 17             | 28.0                   | 29.9                   | 32.2           | 7              | 34.5           | 7              |
| 79216 | ALX  | 75.0           | 11             | 41.9                   | 43.2                   | 50.4           | 14             | 52.1           | 14             |
| 79216 | AMH  | 77.0           | 22             | 80.5                   | 81.5                   | 88.3           | 18             | 90.2           | 18             |
| 79216 | AMR  | 68.0           | 16             | 15.1                   | 15.4                   | 28.1           | 3              | 29.2           | 3              |
| 79216 | ARL  | 100.0          | 12             | 45.3                   | 46.7                   | 50.4           | 14             | 52.1           | 14             |
| 79216 | BAB  | 58.0           | 12             | 85.4                   | 87.1                   | 85.9           | 11             | 88.3           | 11             |
| 79216 | BAD  | 43.0           | 14             | 45.7                   | 46.9                   | 47.2           | 15             | 48.1           | 15             |
| 79216 | BAY  | 71.0           | 12             | 9.1                    | 9.1                    | 35.1           | 10             | 35.6           | 10             |
| 79216 | BER  | 84.0           | 11             | 40.5                   | 42.1                   | 56.4           | 15             | 59.0           | 15             |
| 79216 | BET  | 75.0           | 14             | 23.2                   | 24.3                   | 28.2           | 21             | 29.9           | 21             |
| 79216 | BL1  | 71.0           | 15             | 39.8                   | 40.0                   | 42.6           | 17             | 42.9           | 17             |
| 79216 | BL3  | 67.0           | 15             | 39.8                   | 40.0                   | 42.6           | 17             | 42.9           | 17             |
| 79216 | BL6  | 96.0           | 12             | 35.8                   | 36.6                   | 39.0           | 18             | 39.8           | 19             |
| 79216 | BLG  | 57.0           | 11             | 84.6                   | 85.5                   | 109.0          | 15             | 110.0          | 15             |
| 79216 | BN1  | 76.0           | 9              | 40.4                   | 41.2                   | 41.7           | 14             | 42.8           | 16             |
| 79216 | BNG  | 88.0           | 11             | 36.6                   | 36.5                   | 48.2           | 18             | 48.3           | 18             |
| 79216 | BNW  | 50.0           | 15             | 92.9                   | 99.8                   | 95.3           | 13             | 102.0          | 12             |
| 79216 | BR2  | 68.0           | 12             | 16.6                   | 16.8                   | 32.3           | 3              | 33.2           | 3              |
| 79216 | BRI  | 123.0          | 19             | 14.3                   | 16.8                   | 42.6           | 0              | 45.9           | 4              |
| 79216 | BTH  | 80.0           | 13             | 41.1                   | 42.9                   | 41.1           | 13             | 42.9           | 13             |
| 79216 | BUL  | 105.0          | 17             | 75.9                   | 82.7                   | 86.7           | 16             | 93.6           | 16             |
| 79216 | BVF  | 28.0           | 14             | 45.7                   | 46.9                   | 47.2           | 15             | 48.1           | 15             |
| 79216 | CAN  | 50.0           | 15             | 38.9                   | 39.1                   | 43.6           | 18             | 43.9           | 18             |
| 79216 | CB1  | 75.0           | 15             | 32.2                   | 32.8                   | 34.1           | 12             | 34.9           | 12             |
| 79216 | CB4  | 64.0           | 16             | 32.6                   | 33.4                   | 34.1           | 12             | 34.9           | 12             |
| 79216 | CHL  | 85.0           | 16             | 17.0                   | 17.3                   | 20.7           | 18             | 21.0           | 18             |
| 79216 | CHR  | 75.0           | 15             | 19.9                   | 20.3                   | 22.0           | 11             | 22.4           | 11             |
| 79216 | CHS  | 77.0           | 16             | 15.3                   | 16.6                   | 29.5           | 0              | 31.8           | 9              |
| 79216 | CHT  | 78.0           | 15             | 47.8                   | 51.4                   | 47.8           | 15             | 51.4           | 15             |
| 79216 | CHV  | 78.0           | 13             | 41.1                   | 42.9                   | 41.1           | 13             | 42.9           | 13             |
| 79216 | CKY  | 97.0           | 14             | 35.0                   | 37.1                   | 41.0           | 17             | 43.4           | 17             |
| 79216 | CL2  | 108.0          | 13             | 50.6                   | 51.5                   | 54.6           | 19             | 56.7           | 20             |
| 79216 | CLK  | 90.0           | 17             | 33.7                   | 36.5                   | 34.0           | 12             | 37.1           | 13             |

| DATE  | SITE | $c_{ob}^{max}$ | $h_{ob}^{max}$ | $c_{p0}(h_{ob}^{max})$ | $c_{p1}(h_{ob}^{max})$ | $c_{p0}^{max}$ | $h_{p0}^{max}$ | $c_{p1}^{max}$ | $h_{p1}^{max}$ |
|-------|------|----------------|----------------|------------------------|------------------------|----------------|----------------|----------------|----------------|
| 79216 | CM1  | 90.0           | 12             | 47.0                   | 51.7                   | 55.9           | 16             | 60.3           | 16             |
| 79216 | CM3  | 102.0          | 17             | 95.2                   | 99.7                   | 99.7           | 16             | 105.0          | 16             |
| 79216 | CNE  | 136.0          | 15             | 58.7                   | 58.6                   | 68.8           | 23             | 69.1           | 23             |
| 79216 | CPE  | 55.0           | 10             | 45.4                   | 47.1                   | 57.4           | 13             | 58.2           | 13             |
| 79216 | DAN  | 79.0           | 15             | 0.4                    | 0.4                    | 19.9           | 1              | 20.6           | 1              |
| 79216 | DC4  | 25.0           | 13             | 48.2                   | 49.7                   | 50.4           | 14             | 52.1           | 14             |
| 79216 | DC5  | 140.0          | 13             | 41.1                   | 42.9                   | 41.1           | 13             | 42.9           | 13             |
| 79216 | DC6  | 95.0           | 15             | 38.1                   | 39.7                   | 41.1           | 13             | 42.9           | 13             |
| 79216 | DNR  | 91.0           | 10             | 21.1                   | 21.7                   | 21.1           | 10             | 21.7           | 10             |
| 79216 | DOW  | 80.0           | 13             | 36.5                   | 41.7                   | 39.6           | 14             | 44.6           | 15             |
| 79216 | DRB  | 66.0           | 12             | 1.6                    | 1.6                    | 25.4           | 4              | 26.7           | 4              |
| 79216 | DT3  | 68.9           | 13             | 78.8                   | 79.4                   | 78.8           | 13             | 79.4           | 13             |
| 79216 | DT4  | 38.8           | 13             | 60.1                   | 60.9                   | 92.5           | 10             | 93.7           | 10             |
| 79216 | EB1  | 82.0           | 12             | 67.8                   | 69.7                   | 68.6           | 11             | 70.8           | 11             |
| 79216 | EB2  | 78.0           | 11             | 68.6                   | 70.8                   | 68.6           | 11             | 70.8           | 11             |
| 79216 | ELM  | 2.0            | 23             | 62.7                   | 65.3                   | 62.7           | 23             | 65.3           | 23             |
| 79216 | ERE  | 88.0           | 16             | 66.1                   | 66.3                   | 68.8           | 15             | 68.9           | 15             |
| 79216 | ESS  | 62.2           | 13             | 37.2                   | 37.2                   | 37.3           | 9              | 37.3           | 9              |
| 79216 | ESX  | 98.0           | 16             | 42.0                   | 42.3                   | 42.6           | 17             | 42.9           | 17             |
| 79216 | EXC  | 95.0           | 22             | 40.3                   | 44.0                   | 44.1           | 17             | 44.6           | 17             |
| 79216 | EY1  | 125.0          | 11             | 48.0                   | 50.0                   | 62.3           | 18             | 65.1           | 18             |
| 79216 | FDR  | 100.0          | 13             | 31.1                   | 32.6                   | 33.9           | 10             | 35.2           | 10             |
| 79216 | FLN  | 64.3           | 12             | 35.7                   | 37.5                   | 36.3           | 13             | 38.4           | 9              |
| 79216 | FX1  | 128.0          | 12             | 40.4                   | 40.8                   | 40.7           | 13             | 41.4           | 13             |
| 79216 | FX2  | 117.0          | 12             | 49.5                   | 52.7                   | 49.5           | 12             | 52.7           | 12             |
| 79216 | GAR  | 78.0           | 14             | 13.6                   | 14.1                   | 23.9           | 0              | 24.2           | 0              |
| 79216 | GLN  | 91.0           | 13             | 42.5                   | 44.5                   | 43.7           | 16             | 47.6           | 18             |
| 79216 | GLO  | 33.0           | 16             | 56.2                   | 57.5                   | 57.2           | 17             | 59.0           | 17             |
| 79216 | GMT  | 75.0           | 13             | 42.3                   | 43.8                   | 43.0           | 15             | 44.8           | 16             |
| 79216 | GRE  | 40.0           | 1              | 22.4                   | 23.7                   | 25.6           | 0              | 26.1           | 0              |
| 79216 | GRG  | 37.0           | 9              | 25.3                   | 26.1                   | 52.3           | 17             | 55.4           | 15             |
| 79216 | GRW  | 65.0           | 11             | 15.7                   | 15.9                   | 58.5           | 0              | 62.0           | 0              |
| 79216 | HAR  | 85.0           | 14             | 41.9                   | 41.7                   | 43.8           | 12             | 43.7           | 12             |
| 79216 | HF2  | 85.0           | 14             | 40.5                   | 41.7                   | 41.6           | 13             | 42.5           | 13             |
| 79216 | HGR  | 51.0           | 15             | 24.8                   | 26.7                   | 28.4           | 2              | 31.4           | 2              |
| 79216 | HM1  | 30.0           | 9              | 70.0                   | 72.5                   | 70.0           | 9              | 72.5           | 9              |
| 79216 | HML  | 60.0           | 21             | 68.5                   | 69.2                   | 109.0          | 15             | 110.0          | 15             |
| 79216 | JNS  | 76.0           | 16             | 23.1                   | 24.5                   | 23.1           | 16             | 24.6           | 15             |
| 79216 | KCH  | 75.0           | 23             | 44.1                   | 46.5                   | 73.2           | 8              | 86.4           | 7              |
| 79216 | KNT  | 50.0           | 2              | 24.7                   | 24.9                   | 100.0          | 14             | 102.0          | 13             |
| 79216 | LAN  | 66.0           | 18             | 46.2                   | 49.5                   | 49.4           | 16             | 52.5           | 16             |
| 79216 | LEX  | 60.0           | 17             | 46.9                   | 48.2                   | 49.4           | 16             | 50.7           | 16             |
| 79216 | LIC  | 69.0           | 17             | 46.9                   | 48.2                   | 49.4           | 16             | 50.7           | 16             |
| 79216 | LIV  | 66.8           | 12             | 37.8                   | 38.3                   | 46.1           | 18             | 47.0           | 18             |
| 79216 | LND  | 73.0           | 18             | 45.8                   | 59.0                   | 99.7           | 0              | 107.0          | 0              |
| 79216 | MAM  | 23.0           | 16             | 2.1                    | 2.1                    | 35.5           | 3              | 36.5           | 3              |
| 79216 | MCL  | 67.9           | 12             | 36.4                   | 38.3                   | 37.2           | 13             | 39.4           | 13             |
| 79216 | MER  | 144.0          | 16             | 53.0                   | 58.9                   | 53.0           | 16             | 58.9           | 16             |
| 79216 | MFD  | 29.0           | 15             | 34.8                   | 36.8                   | 39.2           | 12             | 40.1           | 12             |

| DATE  | SITE | $c_{ob}^{max}$ | $h_{ob}^{max}$ | $c_{p0}(h_{ob}^{max})$ | $c_{p1}(h_{ob}^{max})$ | $c_{p0}^{max}$ | $h_{p0}^{max}$ | $c_{p1}^{max}$ | $h_{p1}^{max}$ |
|-------|------|----------------|----------------|------------------------|------------------------|----------------|----------------|----------------|----------------|
| 79216 | MN1  | 96.0           | 11             | 22.8                   | 23.3                   | 34.7           | 19             | 36.0           | 18             |
| 79216 | MNR  | 69.0           | 14             | 45.2                   | 48.7                   | 62.1           | 18             | 66.1           | 18             |
| 79216 | MRC  | 53.0           | 17             | 47.5                   | 55.7                   | 48.2           | 16             | 55.7           | 17             |
| 79216 | MSG  | 76.0           | 10             | 95.2                   | 94.6                   | 107.0          | 17             | 107.0          | 17             |
| 79216 | N10  | 89.0           | 13             | 25.6                   | 26.5                   | 45.1           | 10             | 46.2           | 10             |
| 79216 | NC1  | 100.0          | 16             | 41.0                   | 43.5                   | 41.0           | 16             | 43.5           | 16             |
| 79216 | NC4  | 94.0           | 14             | 52.9                   | 54.7                   | 52.9           | 14             | 55.3           | 15             |
| 79216 | NCL  | 38.0           | 18             | 44.2                   | 47.1                   | 50.1           | 16             | 53.7           | 16             |
| 79216 | NG2  | 83.0           | 23             | 98.7                   | 99.9                   | 107.0          | 19             | 107.0          | 19             |
| 79216 | NRS  | 76.0           | 13             | 32.7                   | 36.2                   | 32.7           | 13             | 36.2           | 13             |
| 79216 | NY2  | 67.0           | 11             | 32.5                   | 33.2                   | 32.5           | 11             | 33.2           | 11             |
| 79216 | NY4  | 45.0           | 10             | 35.1                   | 35.6                   | 35.1           | 10             | 35.6           | 10             |
| 79216 | NY5  | 50.0           | 11             | 27.1                   | 27.4                   | 35.1           | 10             | 35.6           | 10             |
| 79216 | NYK  | 55.0           | 12             | 84.7                   | 84.9                   | 85.1           | 11             | 85.3           | 11             |
| 79216 | OCN  | 85.0           | 13             | 48.5                   | 54.2                   | 52.7           | 15             | 59.7           | 15             |
| 79216 | OK1  | 54.0           | 12             | 79.1                   | 83.7                   | 90.4           | 15             | 94.7           | 15             |
| 79216 | ORO  | 101.0          | 15             | 31.3                   | 33.4                   | 62.3           | 10             | 65.7           | 10             |
| 79216 | OSH  | 79.0           | 12             | 98.4                   | 98.4                   | 99.7           | 13             | 99.6           | 13             |
| 79216 | P10  | 90.0           | 18             | 27.7                   | 28.3                   | 42.9           | 14             | 43.6           | 14             |
| 79216 | PAI  | 62.0           | 15             | 49.6                   | 49.8                   | 68.7           | 19             | 71.6           | 20             |
| 79216 | PH1  | 90.0           | 18             | 31.8                   | 35.2                   | 55.9           | 16             | 60.3           | 16             |
| 79216 | PH2  | 90.0           | 16             | 32.8                   | 33.3                   | 42.9           | 14             | 43.6           | 14             |
| 79216 | PH4  | 70.0           | 13             | 35.6                   | 38.2                   | 47.8           | 15             | 51.4           | 15             |
| 79216 | PH5  | 60.0           | 18             | 27.7                   | 28.3                   | 42.9           | 14             | 43.6           | 14             |
| 79216 | PH6  | 40.0           | 18             | 33.5                   | 36.2                   | 47.8           | 15             | 51.4           | 15             |
| 79216 | PH7  | 130.0          | 18             | 31.8                   | 35.2                   | 55.9           | 16             | 60.3           | 16             |
| 79216 | PLY  | 65.0           | 11             | 39.9                   | 40.5                   | 42.0           | 14             | 43.0           | 15             |
| 79216 | POU  | 42.0           | 18             | 11.0                   | 12.0                   | 31.2           | 8              | 32.6           | 8              |
| 79216 | PRH  | 63.8           | 18             | 69.4                   | 70.0                   | 75.3           | 16             | 77.6           | 16             |
| 79216 | PT2  | 76.0           | 14             | 37.6                   | 37.5                   | 42.1           | 17             | 42.2           | 17             |
| 79216 | PTG  | 87.0           | 11             | 31.2                   | 32.5                   | 46.3           | 23             | 47.6           | 23             |
| 79216 | PTR  | 99.0           | 18             | 82.9                   | 85.3                   | 85.0           | 17             | 87.9           | 16             |
| 79216 | PTS  | 71.0           | 14             | 13.9                   | 14.3                   | 25.4           | 12             | 26.0           | 12             |
| 79216 | PV3  | 32.7           | 2              | 27.0                   | 28.0                   | 36.5           | 6              | 39.7           | 6              |
| 79216 | RDG  | 54.0           | 16             | 33.5                   | 35.3                   | 37.1           | 10             | 39.3           | 10             |
| 79216 | REN  | 105.0          | 15             | 23.6                   | 24.1                   | 32.4           | 19             | 33.2           | 19             |
| 79216 | RVB  | 96.0           | 14             | 46.3                   | 47.4                   | 46.3           | 13             | 47.4           | 14             |
| 79216 | SC1  | 99.0           | 14             | 37.2                   | 37.9                   | 38.3           | 15             | 39.1           | 15             |
| 79216 | SCH  | 85.0           | 12             | 50.6                   | 51.7                   | 55.5           | 16             | 56.4           | 16             |
| 79216 | SCR  | 83.0           | 13             | 82.0                   | 82.4                   | 85.1           | 11             | 85.3           | 11             |
| 79216 | SMC  | 85.0           | 18             | 84.5                   | 90.2                   | 95.6           | 15             | 101.0          | 15             |
| 79216 | SMV  | 112.0          | 17             | 23.8                   | 25.5                   | 48.1           | 3              | 49.9           | 2              |
| 79216 | SR2  | 99.0           | 18             | 69.4                   | 70.0                   | 75.3           | 16             | 77.6           | 16             |
| 79216 | STC  | 59.0           | 12             | 73.7                   | 75.9                   | 104.0          | 18             | 107.0          | 18             |
| 79216 | STH  | 68.4           | 13             | 39.2                   | 40.6                   | 64.5           | 18             | 66.6           | 18             |
| 79216 | STU  | 96.0           | 12             | 33.9                   | 35.1                   | 38.5           | 17             | 39.8           | 16             |
| 79216 | STV  | 89.0           | 13             | 36.4                   | 41.8                   | 36.7           | 12             | 41.8           | 13             |
| 79216 | SVC  | 110.0          | 12             | 40.4                   | 40.8                   | 40.7           | 13             | 41.4           | 13             |
| 79216 | SY1  | 84.0           | 16             | 38.9                   | 39.5                   | 41.7           | 20             | 42.8           | 20             |

| DATE  | SITE | $c_{ob}^{max}$ | $h_{ob}^{max}$ | $c_{p0}(h_{ob}^{max})$ | $c_{p1}(h_{ob}^{max})$ | $c_{p0}^{max}$ | $h_{p0}^{max}$ | $c_{p1}^{max}$ | $h_{p1}^{max}$ |
|-------|------|----------------|----------------|------------------------|------------------------|----------------|----------------|----------------|----------------|
| 79216 | SY2  | 91.0           | 16             | 38.9                   | 39.5                   | 41.7           | 20             | 42.8           | 20             |
| 79216 | SY4  | 91.0           | 16             | 38.9                   | 39.5                   | 41.7           | 20             | 42.8           | 20             |
| 79216 | TL1  | 95.0           | 14             | 40.0                   | 41.0                   | 41.7           | 13             | 42.9           | 13             |
| 79216 | TL4  | 100.0          | 12             | 41.4                   | 42.6                   | 41.7           | 13             | 42.9           | 13             |
| 79216 | TR1  | 92.0           | 12             | 67.8                   | 69.7                   | 68.6           | 11             | 70.8           | 11             |
| 79216 | TR2  | 65.0           | 13             | 82.0                   | 82.4                   | 85.1           | 11             | 85.3           | 11             |
| 79216 | TRN  | 125.0          | 17             | 42.1                   | 42.5                   | 56.3           | 16             | 57.0           | 16             |
| 79216 | UTC  | 104.0          | 16             | 41.4                   | 42.2                   | 41.4           | 16             | 42.4           | 19             |
| 79216 | VIN  | 132.0          | 13             | 50.7                   | 56.8                   | 86.1           | 20             | 101.0          | 19             |
| 79216 | WH2  | 63.8           | 14             | 36.5                   | 39.3                   | 40.0           | 16             | 43.0           | 16             |
| 79216 | WLK  | 73.0           | 13             | 28.0                   | 29.2                   | 32.4           | 9              | 33.8           | 9              |
| 79216 | WNS  | 74.0           | 11             | 89.0                   | 89.9                   | 92.5           | 10             | 93.7           | 10             |
| 79216 | W01  | 55.0           | 16             | 28.2                   | 28.9                   | 29.1           | 17             | 29.7           | 17             |
| 79216 | W02  | 68.0           | 17             | 29.1                   | 29.7                   | 29.1           | 17             | 29.7           | 17             |
| 79216 | WRN  | 100.0          | 15             | 58.3                   | 58.9                   | 78.8           | 13             | 79.4           | 13             |
| 79216 | WSL  | 120.0          | 10             | 40.1                   | 40.1                   | 75.9           | 15             | 76.0           | 15             |
| 79216 | YG2  | 81.0           | 15             | 36.2                   | 37.2                   | 39.8           | 19             | 41.2           | 19             |

# GLOSSARY

| <u>Symbol</u>                         | <u>Definition</u>                                                                                                 |
|---------------------------------------|-------------------------------------------------------------------------------------------------------------------|
| $c_{ob}$                              | Observed hour-average $O_3$ concentration at a given receptor at a given hour                                     |
| $\overline{R}_{c_{ob}}$               | Average value of $c_{ob}$ over all receptors at a given hour                                                      |
| $c_{ob}^{max}$                        | Maximum value of $c_{ob}$ during a daily period at a given receptor                                               |
| $\overline{R}_{c_{ob}^{max}}$         | Average value of $c_{ob}^{max}$ over all receptors at a given hour                                                |
| $c_{p0}$                              | Predicted ROM1 layer 0 hour-average $O_3$ concentration interpolated to a given receptor location at a given hour |
| $\overline{R}_{c_{p0}}$               | Average value of $c_{p0}$ over all receptors at a given hour                                                      |
| $c_{p0}^{max}$                        | Maximum value of $c_{p0}$ during a daily period at a given receptor location                                      |
| $\overline{R}_{c_{p0}^{max}}$         | Average value of $c_{p0}^{max}$ over all receptors at a given hour                                                |
| $c_{p0}(h_{ob}^{max})$                | Value of $c_{p0}$ at the hour of occurrence of $c_{ob}^{max}$                                                     |
| $\overline{R}_{c_{p0}(h_{ob}^{max})}$ | Average value of $c_{p0}(h_{ob}^{max})$ over all receptors at a given hour                                        |
| $c_{p1}$                              | Predicted ROM1 layer 1 hour-average $O_3$ concentration interpolated to a given receptor location at a given hour |
| $\overline{R}_{c_{p1}}$               | Average value of $c_{p1}$ over all receptors at a given hour                                                      |
| $c_{p1}^{max}$                        | Maximum value of $c_{p1}$ during a daily period at a given receptor location                                      |
| $\overline{R}_{c_{p1}^{max}}$         | Average value of $c_{p1}^{max}$ over all receptors at a given hour                                                |
| $c_{p1}(h_{ob}^{max})$                | Value of $c_{p1}$ at the hour of occurrence of $c_{ob}^{max}$                                                     |
| $\overline{R}_{c_{p1}(h_{ob}^{max})}$ | Average value of $c_{p1}(h_{ob}^{max})$ over all receptors at a given hour                                        |

| <u>Symbol</u>       | <u>Definition</u>                                                                                                                                                |
|---------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $c_{p1-A}^{\max}$   | Maximum ROM1 layer 1 predicted $O_3$ concentration during a daily period at the same receptor location where $c_{ob}^{\max}$ occurred within a given $O_3$ plume |
| $c_{p1-B}^{\max}$   | Maximum ROM1 layer 1 predicted $O_3$ concentration during a daily period at any receptor location within or near a given $O_3$ plume                             |
| $c_{p1-C}^{\max}$   | Maximum ROM1 layer 1 predicted $O_3$ concentration during a daily period at any grid cell within or near a given $O_3$ plume                                     |
| $d_0$               | $= c_{ob} - c_{p0}$ . Residual difference (bias) between observed and predicted $O_3$ concentrations at a given receptor location at a given hour                |
| $R_{d_0}$           | Average value of $d_0$ over all receptors at a given hour                                                                                                        |
| $R_{ d_0 }$         | Average value of absolute $d_0$ values (gross error) over all receptors at a given hour                                                                          |
| $d_{AO}^{\max}$     | $= c_{ob}^{\max} - c_{p0}(h_{ob}^{\max})$                                                                                                                        |
| $R_{d_{AO}^{\max}}$ | Average value of $d_{AO}^{\max}$ over all receptors at a given hour                                                                                              |
| $d_{BO}^{\max}$     | $= c_{ob}^{\max} - c_{p0}^{\max}$                                                                                                                                |
| $R_{d_{BO}^{\max}}$ | Average value of $d_{BO}^{\max}$ over all receptors at a given hour                                                                                              |
| $d_1$               | $= c_{ob} - c_{p1}$ . Residual difference (bias) between observed and predicted $O_3$ concentrations at a given receptor location at a given hour                |
| $R_{d_1}$           | Average value of $d_1$ over all receptors at a given hour                                                                                                        |
| $R_{ d_1 }$         | Average value of absolute $d_1$ values (gross error) over all receptors at a given hour                                                                          |
| $d_{A1}^{\max}$     | $= c_{ob}^{\max} - c_{p1}(h_{ob}^{\max})$                                                                                                                        |
| $R_{d_{A1}^{\max}}$ | Average value of $d_{A1}^{\max}$ over all receptors at a given hour                                                                                              |
| $d_{B1}^{\max}$     | $= c_{ob}^{\max} - c_{p1}^{\max}$                                                                                                                                |
| $R_{d_{B1}^{\max}}$ | Average value of $d_{B1}^{\max}$ over all receptors at a given hour                                                                                              |

| <u>Symbol</u>                              | <u>Definition</u>                                                                                          |
|--------------------------------------------|------------------------------------------------------------------------------------------------------------|
| $d_{pl-A}^{max}$                           | $= c_{ob}^{max} - c_{pl-A}^{max}$                                                                          |
| $d_{pl-B}^{max}$                           | $= c_{ob}^{max} - c_{pl-B}^{max}$                                                                          |
| $d_{pl-C}^{max}$                           | $= c_{ob}^{max} - c_{pl-C}^{max}$                                                                          |
| $(d_{pl-A}^{max}/c_{ob}^{max}) \times 100$ | Percent bias between $c_{ob}^{max}$ and $c_{pl-A}^{max}$                                                   |
| $(d_{pl-B}^{max}/c_{ob}^{max}) \times 100$ | Percent bias between $c_{ob}^{max}$ and $c_{pl-B}^{max}$                                                   |
| $(d_{pl-C}^{max}/c_{ob}^{max}) \times 100$ | Percent bias between $c_{ob}^{max}$ and $c_{pl-C}^{max}$                                                   |
| $h_{ob}^{max}$                             | Hour of occurrence of $c_{ob}^{max}$                                                                       |
| $h_{p0}^{max}$                             | Hour of occurrence of $c_{p0}^{max}$                                                                       |
| $h_{p1}^{max}$                             | Hour of occurrence of $c_{p1}^{max}$                                                                       |
| $n$                                        | Number of receptor monitoring sites for $O_3$ reporting values at a given hour                             |
| $R_{Sd0}$                                  | Standard deviation of the residual differences (noise) over all receptors at a given hour for ROM1 layer 0 |
| $R_{Sd1}$                                  | Standard deviation of the residual differences (noise) over all receptors at a given hour for ROM1 layer 1 |
| $R_{SdA0}^{max}$                           | Standard deviation of $d_{A0}^{max}$ over all receptor locations                                           |
| $R_{SdA1}^{max}$                           | Standard deviation of $d_{A1}^{max}$ over all receptor locations                                           |
| $R_{SdB0}^{max}$                           | Standard deviation of $d_{B0}^{max}$ over all receptor locations                                           |
| $R_{SdB1}^{max}$                           | Standard deviation of $d_{B1}^{max}$ over all receptor locations                                           |